OCEANOLOGY SERIES NUMBER 1

MAN IN COLD WATER MAY '69

Co-sponsored by
Department of
Industry Trade & Commerce
AND
McGill University

Published
in cooperation with
Sea Harvest & Ocean Science

DECEMBER, 1969

MAN IN COLD WATER

A CONFERENCE ON

Undersea Operations In The Canadian Environment

HELD AT McGILL UNIVERSITY

MONTREAL, QUEBEC — MAY 12-13, 1969

CONTENTS

CONFERENCE COMMITTEE

Chairman: Mr. M. J. Colpitts, Aerospace, Marine & Rail Branch,
Department of Industry, Trade and Commerce
Secretary: Dr. E. F. Roots, Co-ordinator, Continental Shelf Project
Department of Energy, Mines and Resources

Mr. B. Ackerman, Consultant,
Northern Associates Reg'd.
Dr. J. M. Anderson, Dir. St. Andrews Biolog. Stn.
Fisheries Research Board of Canada.
Dr. M. J. Dunbar, Asst. Dean of Grad. Studies
& Dir., Marine Science Centre, McGill Univ.
Mr. R. A. Krajewski, Aerospace, Marine & Rail Br.
Dept. of Industry, Trade & Commerce.

Dr. F. C. MacIntosh, Physiol. Dept., McGill Univ.

Mr. F. Misner, Manager, Garrett Marine.

Dr. E. R. Pounder, Director, Ice Research Program
Dept. of Physics, McGill University.
Mr. J. C. Ruse, Director of Underwater Systems
Spar Aerospace Products Limited.

CO-SPONSORED

McGILL UNIVERSITY — DEPARTMENT OF INDUSTRY, TRADE & COMMERCE

May 1969

COLD WATER AND MAN

by Dr. E. F. Roots*

Ladies and gentlemen: this is to be an exploratory conference, and none of us knows in what direction it might lead. My task as keynote speaker seems to be one of talking about cold water without at the same time throwing cold water on our subsequent proceedings. My only qualification for attempting to do this is a demonstrated capacity for getting into hot water over matters having to do with cold regions.

Background

This conference, like most that have developed in response to a growing need, did not come about suddenly, but evolved over a number of years. It was first proposed a little more than five years ago, in a tent on the sea ice of Queen Maud Gulf in the Canadian arctic archipelago. March was stormy in the Arctic that year, and during that trip the temperature was mostly colder than thirty-five degrees below zero, once dropping to -54°F. We were a varied crew, — some are here today, serving on various panels, and their names are on your programme — and we included:

— a navy diver, with extensive cold-water and sub-ice experience;

— a senior engineer from an international drilling company, who specialized in Arctic drilling problems;

— a hydrographic surveyor;

— a geophysicist;

— and a geologist.

We had a variety of reasons for being in the north that spring; most of us were on our way to the prosaic but practical field work that makes up most of industrial or government activity in the north. But what brought us together in the tent on Queen Maud Gulf was an objective quite impractical, although it was exciting. We were looking for the remains of Sir John Franklin's ship, which had disappeared 120 years before. By running traverses across the ice and using a magnetometer, echo-sounder and ice drill, we hoped to do a more efficient job of searching for the remains of the ship than we could have in the summer after the ice had gone. Naturally, we had many discussions and plans about how we would examine the submerged wreck if we found it. In the tent, or traversing across the ice in subzero weather, we were very conscious that only 8 feet below us the environment was at least fifty degrees warmer. Was it not possible to make more use of this comparatively balmy environment?

At that time, underwater techniques applicable to cold waters were advancing rapidly, and we discussed the need to make these techniques known to those who might make use of them. Some problems that might best be solved by underwater operations in the Arctic were becoming apparent, and if Arctic development proceeded as promised, might rapidly become specific and compelling. It was clear that, at least in the civilian world, those who were developing underwater techniques and equipment were in the main a quite different group of people from those who had practical problems in Canadian waters that might be solved using underwater activities. One group was asking: "Who wants underwater information badly enough, or sees a potential reward sufficiently great, to be induced to spend money on underwater operations?" The other group was, we felt, either unaware of the possibilities of underwater operations or else had an unrealistic Sunday-supplement optimistic impression that techniques just around the corner would make submarine activities as commonplace and as cheap as those on land. We felt there was a need to get the two groups together for some realistic talk, and wondered if it would be feasible to organize a conference to bring this about.

The same group, and some of our friends, discussed the idea from time to time; then, a little more than a year ago, three of us met in Montreal specifically to discuss the advisability of organizing such a conference. By this time, the scene had changed somewhat:

(i) There had been significant advances in our knowledge of marine geology and of the oceanographic environment, particularly in the polar areas; and in the knowledge of man's ability to live and work there;

(ii) Underwater technology had developed rapidly, and there were in Canada a growing number of underwater equipment manufacturers and specialists. Most of this development had come about as a result of defence spending, but there were signs that military support would be tapering off. Many undersea items were being declassified and were becoming generally available, and the undersea industry was looking for civilian business.

(iii) There was a real smell of money in the ocean and in the North. The Gulf of Mexico, California, and the North Sea had proved that you could make money from the ocean by other ways than fishing, if you knew your underwater business. The signs of oil were so insistent and so favourable on the North Slope of Alaska and in the Canadian Arctic that it was not so much a question of *whether* or *if*, but simply *when* we would be in the oil business there. There was active exploration for subsea wealth off Nova Scotia, the Queen Charlotte Islands on the west coast, in Hudson's Bay, and programmes were being planned off Labrador and Baffin Island.

All of this gave promise of a real demand for a cold-water underwater capability in Canada in the very near future. The time for a thorough discussion of these problems seemed to be ripe; McGill University and the Department of Industry were receptive to the idea — so here we are!

The concept of the conference

The basic objective of this meeting is to attempt to bridge the growing gap, or potential gap, between those who are knowledgeable about underwater operations — that is, those who know about the physiological possibilities and limitations, the techniques, the equipment and the costs — and those who have problems or activities to which underwater operations could be usefully applied.

This distinction between the gadgeteer and the user, between the inventor and the consumer, is characteristic of our technological society. Think of the helicopter; it was quite highly developed as a vehicle before there was any real conception of its role in transport. You may remember, when helicopters first came on the scene, the discussions on their possible uses — all sorts of suggestions were advanced; like painting smokestacks, and vertical taxis to cut down congestion in skyscraper office elevators. These functions were technically possible, but no one could have built an industry out of them. The helicopter industry thrives today on quite different but generally less exotic uses for its product. There are many other examples. Today, for instance, we have quite capable air cushion vehicles but no clear idea how they will fit into our industrial or economic picture; and we are watching with interest the struggle in the space programme between the engineers who want to develop and test more and better equipment before they use it for anything, and the scientists who want to use existing equipment to survey the earth, or study the planets.

The underwater field is much more complex than that of, say, helicopters or air cushion vehicles, for it embraces subjects ranging from oceanography to medicine to engineering to amateur sport; and the gadgetry (if I may again use that flippant word for what some here have been most seriously spending their lives on) is so absorbing and so specialized that it develops a different breed of men and a different kind of business from those who use the results of these gadgets and their

*Coordinator, Polar Continental Shelf Program, Dept. E.M. & R.

operations. A homely analogy might be made between underwater operations and high-fidelity sound equipment. I think that most of us here will agree that one of the greatest triumphs of sound technology is its ability to reproduce music with a purity and control that had not heretofore been possible. But how many of the people who are really enthusiastic about putting together hi-fi equipment are knowledgeable musicians? Many, until recently, seemed to be equally interested in being able to reproduce a squeaky gate on stereo. And how many musicians of real stature have so far composed worthwhile music specifically to exploit the full potential of high fidelity sound equipment? Again, the answer is few or none. But, as high fidelity equipment has become more commonplace and less experimental, there are an increasing number of people who use it as a means to an end, and not an end in itself, and the world of music is enriched. We must try to bring about a similar development in the use of underwater equipment in Canada. I do not mean to imply that in the field of underwater operations we have a group of Beethovens on one side and a tweeter-breadboard gang on the other. The situation is simply that there is emerging a whole new series of instruments and abilities in the underwater field in Canada; and at the same time there is promise, in Canada and other cold-water areas of the world, of uncovering, with the help of underwater operations, new knowledge and new resources of value to the community. We want to do our best to ensure that these two processes develop in contact and in harmony with one another.

This conference is not intended to be a series of lectures. It is planned to present brief reviews of selected general subjects as listed on the programme; and these will be followed by active discussion on that subject and the more particular or specific aspects into which it may lead. We want everyone, the newcomer as well as the expert, to feel free to contribute to the discussion, for this is a meeting to explore how little we know about one another's field as well as to expound on the current state of knowledge. For purely practical reasons, we have structured the programme to be centred around problems instead of around techniques. If we had focused on techniques, starting, say, with diving, we would be discussing the problems and advances of diving first in regard to resource industries, then in regard to communications, then in research, etc.; then when we proceeded to underwater vehicles we would have to go through their problems and advances with regard to resource industries, communications, research, etc. That seemed to us to be a difficult way to organize a hard-hitting programme. Also, to keep from getting too far afield, off into the realm of space ships and remote sensing and so on, we want to keep the focus of discussion on the activities by which man himself gets beneath the surface. We do not intend to be strict about this, but in order to keep some unity to our discussion, I hope that you will keep in mind that the conference is on *man* in cold water.

The Canadian underwater environment

What is special about the Canadian underwater environment? There have been a number of conferences on different aspects of marine technology, exploiting the ocean, man in the sea, and so on; and the question might properly be asked, "Why one more?" These other meetings, for reasons of their own, have not focused on problems of the kind faced by the Canadian marine equipment industry, nor have they dealt satisfactorily with the problems faced by the scientific agencies or the resource industries in Canada that are becoming interested in going down to the sea and beneath it. These problems appear to be sufficiently distinctive, and important in the national context, to justify a conference. From the very large attendance here this morning it would appear that a lot of you think so too.

Canada has been described, not inaccurately, as a country where there is too much water on the land, too much ice on the water, and all the women are lined up along the southern border. In that description is the reason for this conference. In this country we have a great deal of contact with water, much more than some of us realize, both along our coasts and inland. Much of the water is cold or icy and most of the water is remote (and there is no better criterion for remoteness than distance from large numbers of women). We are also fond in this country of using superlatives of doubtful accuracy. You have heard it is claimed, for instance, that Canada has more fresh water than any other land in the world. This statement is open to argument. All one has to do is to look at Antarctica to see many many times more fresh water. There is one lake in the Soviet Union which may very well have more non-salty water than all the lakes in Canada. It is probably true that we have a greater *surface area* of freshwater lakes than any other country. You have also heard it claimed that Canada's shoreline is the longest of any country. I will not comment on this except to say that it would be a real labour of love to prove it; and there may be a few surprises from other countries. What is unique and unchallengable, however, is that most of our shoreline, internally and externally, is ice-bound for at least part of each year.

In the underwater field, these peculiarities of the wet environment of Canada might be turned to our advantage. What we have in Canada that other nations who are advanced in underwater subjects do not have, is *cold water*.

It is not unlikely that the need for and the importance of cold-water activities in both hemispheres will increase sharply in the near future. In this field Canada has experience of the problem, a fair amount of basic and applied research already accomplished, and lead time in the development of equipment. This country cannot expect to compete with the U.S.A. and Europe in the general oceanographic equipment field, although, of course, there is no reason why we should not be able to carve a good niche for ourselves here and there. But we could well become specialists and leaders in cold water applications, to the extent that these are unique and there is a demand for them anywhere. To draw an analogy again, it would be unrealistic for us to try to dominate the world automobile industry, but we do have a chance to become world leaders in snowmobiles. The same opportunity to be the leader in fields that are peculiarly ours applies to cold water underwater equipment and techniques.

Cold water

We have been talking about cold water — what do we mean by it? A popular definition, and one that seems to be followed by the majority of the world's oceanographers, is that any water cooler than that found off California or Florida is cold; you might say that there is sort of a cut off below the bikini line. For our purposes we will define cold water as that water in which loss of heat from men or equipment becomes an important factor in the operation or activity. Dr. McIntosh, Dr. Anderson and others here will, I am sure, supply you with quantitative information on this question during the next two days.

The structure and distribution of cold water masses

Where does one find this cold water? It is important to consider its distribution in three dimensions and in time. Most of us, when we think of bodies of water, habitually think of the *surface layer*. That is the layer we swim in, sail or ski or play hockey on, generally drink from and dump our sewage into. It is also the layer where most of the modification of water composition and character occurs, as fresh water or chemicals are added or subtracted, heat and gases are taken in or given off, and photosynthesis is concentrated. This surface layer can be classified as cold water, according to our definition, all around the coasts of Canada throughout the year, except for Juan de Fuca Strait and parts of the Strait of Georgia, and over all the inland bodies of water in Canada except for about three months in the summer in the southern quarter of the country. In Canada we have two main coastlines: one runs roughly from Herschel Island, N.W.T. to Passamaquoddy Bay, N.B., and the other from Stewart, B.C. to White Rock, B.C.; along nearly all the former, much longer, coastline, as along the shores of almost all our inland waters, the surface layer is solid on top for part of every year. In summer, however, in inland or protected areas the surface layer may heat very rapidly, so that the water temperature may be 15-20°C (30-36°F) warmer than in the winter. This wide annual fluctuation of temperature of the surface layer, punctuated by a change of phase to the solid state, while a normal Canadian experience, is an unusual behaviour compared to that of most of the world's water masses; and it is not a situation encountered by most people or agencies engaged in underwater activities. Underwater operations or studies in Canada must deal with this phenomenon, which is at once a problem, a challenge, and an opportunity to take the initiative in research and development.

Below the surface layer, in nearly all Canadian waters, there is colder water. Usually the temperature drops several degrees in first few tens or couple of hundred feet. Oceanographers and limnologists call this region of rapidly decreasing temperature with depth the *thermocline layer;* and the nature of the thermocline, — that is, the pattern in which the temperature decreases with depth — may vary from place to place or from season to season and tells a lot about the character and behaviour of the water body. Everywhere in or around Canada, at the base of the thermocline layer, or in the underlying *deep water layers,* the waters must be classified as cold, with negligible seasonal fluctuations.

The unique characteristics of cold waters

In what ways are cold water unique? Many of the things I am going to say here are obvious, and some of my generalizations will no doubt offend some oceanographers present, but I hope they will help put our subsequent discussions into perspective. At one end of the cold water spectrum of course is the fact that when water gets cold enough it freezes. The annual change of the surface of water into ice has been a more important factor in determining the character of Canada than we often realize. At every level, from the leaching of our soils and the quality of our crops, from the migration of our wild geese and of our free-spending tourists, from the location and economic cycle of our ports and our building construction codes, to our tariff policies, freight subsidies, and Winter Works programmes, — all are influenced by this drastic annual change of phase of the surface of the water.

But the process of freezing is not something which affects the surface alone. As everyone here knows, when water cools, it gets progressively heavier, and sinks, until it has cooled to a temperature of about 4°C (39°F); then on further cooling it expands, becomes lighter and rises to the top. Thus ordinarily the water comprising every particle of ice has, during the cooling and freezing process, been down to some depth (in a lake, often to the bottom) and up again. The result is an *annual turnover* of a body of water which freezes. This process has a strong influence on the chemical and biological reactions in the surface and thermocline layers of the ice-covered ocean, and in nearly all the lakes and rivers of Canada.

Another basic process to keep in mind is the consequence of the well-known fact that when water freezes, the pure water freezes first because it has a higher melting point than a solution of salts. Thus the ice is always more pure than the solution left behind. How pure it is, will of course depend on how fast it freezes, how still the water is, and other factors. If the ice melts and re-freezes again, the second-generation ice will be purer water than the first generation, and so on. This process is the reason why sea ice three years or more old is generally fit to drink.

As the ice freezes the impurities, or whatever was in the original solution, become concentrated in the remaining liquid. Any true native of Labrador uses this process to improve the quality of cheap whiskey. In nature, most of the impurities become heavier than the surrounding water and sink. There is what is popularly called a "rain" of impurities, mostly ions of dissolved salts and organic compounds, through the upper layers of water during the winter as ice continues to form. These impurities descend to a level equal to their density and collect there, unless removed by currents or mass transport. When the ice melts in the spring, it releases a flood of light, relatively pure water which tends to stay on the surface until mixed or dispersed by some other process. The net result of cooling, freezing, and melting of the surface layer is to create a layered structure in the water, with a pronounced annual vertical movement of water and chemicals in each layer. Each layer naturally is denser than the one above; the density difference may be due to differences of temperature, or of salinity, or both, and there are often surprisingly sharp boundaries between the layers.

The effect of the ice cover

There is one other characteristic of cold waters that we should keep in mind. That is the effect of the ice cover itself. The ice has many obvious effects, of course, besides being able to support hockey players and cocktail lounges. For one thing it greatly reduces the effect of wind and production of waves in the ocean, and this will have important consequences when we come to consider, for instance, pollution control in the Arctic. It reduces drastically the absorption of solar heat into the ocean, and this is all the more important because of the relatively small amount of heat received in most ice-covered areas. However, what heat does get absorbed may often be trapped beneath the ice. There can develop as a result a "green-house" process, where the absorbed radiation is reflected internally, giving, when conditions are right, a marked rise of temperature. The most outstanding examples of this process are the lakes in the dry valleys of Antarctica; Lake Vanda, for instance, is perennially covered with 12 to 16 feet of ice, but its temperature at the bottom is about 55°C (130°F), due to the accumulated very weak solar radiation. We do not know of any such spectacular effects in Canada, but everywhere the ice cover reduces the loss of heat and water vapour from the water to the atmosphere. The heat loss from open water is often an order of magnitude greater than that from a surface covered with ice. Therefore, if there is a body of water covered with ice but with a few cracks and gaps amounting to about 1/10 of the total surface, most of the heat loss will be through the cracks and gaps. It is this sudden change of heat and moisture transfer when even a small amount of open water appears that leads to the production of the common Arctic summer fog and stratus cloud. The fog and clouds of course further reduce the amount of heat received and absorbed by the water body. As well as insulating against the transfer of heat, the ice cover effectively prevents the penetration of sunlight into the waters. Basic biological production is therefore reduced to a very low level in ice-covered waters.

The circulation of cold water masses

Let us look at some of the larger scale characteristics of cold water masses. If we consider whole oceans, the change from moderate temperatures to cold occurs over distances which, horizontally are fractions of the size of the earth and which vertically divide the oceans into three or four main layers. The broad changes in the surface layer temperatures are as everyone knows, not directly related to latitude: the Gulf of Alaska is much farther north than the Gulf of St. Lawrence but is considerably warmer, and Hudson Bay has many features more Arctic than the Beaufort Sea even though it is 1,000 miles farther south. However, it may be not the absolute temperature, but the *temperature contrast,* which is important in determining the characteristics of cold water masses. The water of the Gulf Stream system, for example, is quite a bit colder off the coast of Norway than it is off the coast of Florida; but north of Norway it still has enough differential heat, compared with that of the surrounding seas, to be a major factor in influencing the two counter-rotating currents that comprise the surface circulation of the Arctic Ocean. Just a fortnight ago I returned from the Arctic. In the course of our work there we had a camp on the sea ice very close to the North Pole. The temperature and the scenery, of course bore little resemblance to that of the Bahamas, but it was intriguing to record our drift — anything from ½ to 3½ miles per day — , and to speculate that our course was in part determined by the effects of Caribbean sunshine.

Some of the characteristics of cold oceans are due to the mechanical movement of water masses. When the water is colder, it is denser and it sinks and is overridden by lighter, warmer water. The most spectacular example of this is the Antarctic convergence, where the cold waters flowing northward from the pack ice zone surrounding the Antarctic continent meet the relatively warmer waters from lower latitudes and sink beneath them. At the same time, just behind the line of convergence there is an upward welling of waters from deeper levels, and thus there is a zone of concentration of chemicals and nutrients. The sub-antarctic waters are therefore biologically very productive. Such a line is not as well or as continuously defined in the northern hemisphere because of the geographical pattern of continents and oceans; but in the North Atlantic ocean, for instance there is a mass of cold water, the Atlantic Deep Water, that sinks beneath the surface in the subarctic and creeps southward as a great wedge, crossing the equator and fingering its way between the still colder northward-creeping blanket of Antarctic Bottom Water and the slightly less cold Antarctic Intermediate Water. A familiar but dramatic surface effect is the meeting of the cold Labrador current with the comparatively warm fringes of the

Gulf Stream System near the Grand Banks of Newfoundland; the result is both fog and fish.

Chemical aspects

Other aspects of cold ocean waters are chemical. One of the most remarkable features of the oceans is that despite the influence of climatic zones and the effects of land drainage into the sea, the mixture of salts in sea water is nearly the same throughout the world; the ions appear in nearly constant ratio to one another. When the salt content is locally raised due to the formation of sea ice, or when it is lowered by melting of ice or flooding by spring run-off, the salt content changes on a per-weight basis, and the ionic ratios remain unchanged except in the immediate area of discharge of a large river. This constancy may help give us a sense of proportion, for it is apparent that at any one time, in any given situation, cold water can dissolve more carbon dioxide, less of most salts and have a distinctly slower electrolytic exchange rate, than warm water. The differences in behaviour, over the temperature ranges we are discussing, may seem small in the laboratory, but over areas which are parts of oceans in size, and taking into account the rate of water circulation, these differences could result in profound changes in the sea or its deposits. Cold water is in general a better ionic insulator than warm water. Some people have thought about the possibility of using natural temperature differences to control a differential disposition of metallic salts on the ocean floor. At our present stage of knowledge, it is hard to see much promise in these schemes; but maybe we don't yet know enough of the physical chemistry of the sea.

Life in cold waters

The effect of cold waters on life in the sea is naturally very complex. Most chemical and biological reactions are slower with lower temperatures. On the other hand, the circulation of cold waters may result in local concentrations of nutrients. The higher solubility of carbon dioxide in cold waters may, if I may grossly oversimplify, make it harder for shellfish but easier for algae.

You will probably hear a good deal in the next couple of days about the *primary productivity* of cold waters. This is a term which denotes, in effect, the ability of the ocean to transform carbon into living organic forms — phytoplankton — which can, if circumstances are favourable, become the first link of the chain of life in the ocean. There are many factors of cold waters besides temperature and chemistry that affect primary productivity. We know just enough about the penetration of light into Arctic seas to have uncovered some real puzzles. Waters which freeze and are then covered with snow are necessarily dark for much of the year; and in high altitudes even if not covered by ice they are continuously dark for some months in winter and continuously light for a corresponding period in summer. The growth of algae normally depends on photosynthesis, yet there is some evidence that Arctic algae may go through important parts of their life cycle without the benefit of any measurable amount of light. In temperate and tropical waters the plankton carry out a ceaseless daily migration to the surface and back down to a depth of a few metres. This has commonly been explained as a normal day-and-night cycle, tied to the variation in daylight and the requirements of photosynthesis. But in the Arctic plankton still go up and down once every day, at least in summer, carrying on their 24-hour cycle even though there is negligible variation in light intensity. Now is this an inherited habit, just like that of the Eskimos who have a summer day that is three months long but still get up a hundred times during the night, or is there another more direct cause? If phytoplankton have an inherited instinctive behaviour, what does that teach us about the nature of inheritance, and about instinct?

Species that thrive in cold water conditions are often specially adapted to those conditions, and are restricted to those parts of the environment where such conditions are found. The net effect on life in the cold oceans and inland waters is that there are fewer species, although there may be very numerous individuals of the successful species. As with the mosquitoes and caribou on land, as one goes north to lower temperatures one encounters less complex, more vulnerable communities, with nearly pure populations fluctuating between prosperity and near-extinction.

In the high Arctic the conditions at the shoreline are particularly critical. Most bodies of water have an air-water interface as large as the body itself, across and under which the whole complex of life processes can take place. When the water is ice-covered throughout all or most of the year, the effective air-water reaction area is reduced to a thin line along the shore — the "shore lead" —, plus such other cracks and patches of open water as may develop as the ice moves or decays. It is along the shore lead that nutrients are concentrated, and light enters the water; here bottom-dwelling organisms can thrive and marine carnivores and scavengers, from copepods to polar bears, can make a living. It is also the zone most sensitive to poisoning and pollution. Although we do not yet know enough to know what to do about it, it seems clear that damage to the shoreline zone in the high Arctic would have a far greater relative effect on the total marine life in the area than would similar damage to the shoreline of a temperate ocean or lake.

Changes with time

There is one further aspect of the behaviour of cold water that should be kept in mind; this has to do with the way the underwater environment may change with time. We all know that water bodies have a higher heat capacity than the surface of the land. They therefore have a stabilizing or moderating effect on short-term changes in the environment. But the water can change its behaviour much faster than the land. The cliffs of Mount Royal outside this building are being shaped by water and frost. If the Montreal climate were to change drastically, it would still take many decades for the effect to show on the cliffs; but eventually they would show it, and they would continue to show it long after the climate had changed again. In contrast, the oceans can change character quickly and without leaving apparent trace of their former condition. Between 1956 and 1957 the surface waters of the eastern Pacific cooled 7°C (13°F). One result that humans noticed was that no albacore came far enough east to be caught by the American fishing fleet. A few years later the temperature and the albacore were back to "normal", and there was little obvious evidence of what had happened. As one eminent oceanographer has said, "The ocean has no memory." There are also longer term changes that have affected human history or the evolution of our planet, for which changes in the ocean seem to have been partly responsible or at least an agent. A thousand years ago, for instance, the Vikings crossed the North Atlantic to Greenland in open boats and had relatively little difficulty with sea ice. They established thriving colonies in Greenland and lived by sheep farming and fishing. We are not concerned here with the reasons for the abandonment of those colonies by Europe, but as far as Greenland was concerned, some time about the fifteenth century the seas became colder on both coasts of the island. Sea voyages became so difficult, and the farms so unproductive, that it was not possible or did not pay to maintain regular trade with Europe. As the sea cooled, the cod fisheries disappeared, and an arctic marine fauna took its place; the climate became more severe, and the economy moved from one based on farming and fishing to one of seal-hunting, in the very same location within a few generations. These conditions have persisted until the present century. But within the last three decades there has been a dramatic change. The seals are moving north, and the codfish are coming back in ever increasing numbers. In southwest Greenland the growing season is a few days longer each year, and farms abandoned for six hundred years are being rehabilitated. The Greenlanders are justifiably proud of the thriving new industries they are building. It took modern technology, wise planning and investment, and education to bring this about; but it also needed a bit of help from a change in the ocean itself.

The effect of cold waters on human endeavours

Although it is obvious that man has had to deal with the cold water environment for as long as he has been living in the North Temperate Zone, specific examples of the effects of cold water on the historical development of our civilization are hard to isolate. Some scholars have speculated on the effect that the freezing of Bering Strait may have had on the original migrations to the Americas. The northern maritime peoples, including the Vikings and their successors, the Scots, the Eskimos, the Aleuts, the Japanese, and the

coastal tribes of eastern Siberia, have each developed distinctive cultures and technologies in response to their version of the cold water environment. To remind us that little is new, even in technology, we should recall that the Romans made effective use of the Alexbow principle when manoeuvring on ice-covered lakes in galleys equipped with underwater rams.

Let us now consider some of the things we might touch on as we discuss modern underwater activities in the cold water environment.

Fuels and minerals

Except for possible changes in deposition or alteration of chemical sediments, the difference between warm and cold waters as they affect the occurrence and exploitation of fuels and minerals is not one of substance but merely of degree; — it is a matter of cost, convenience, and practicability. The difficulties imposed by the cold water environment in the discovery and extraction of fuels and minerals are mostly those of the associated environment above sea level; these are factors of climate, remoteness, and their corollary of high costs. All of these factors are in some degree due to the cold water. Theoretically at least in most Arctic areas it should be more comfortable, both for machinery and for people, below sea level than above it. So we should consider the relative possibilities and problems of, for example, a submerged drilling camp versus a frozen-in barge in the sea ice. Activities connected with mineral exploration and development offshore will in any case require the development of underwater surveying, construction, and maintenance skills suited to a cold region. Who is going to develop these, and how? It is clear that the costs of underwater activities are going to be high, in dedication and experimentation as well as in dollars; but there is promise that the returns will be even higher, and there is little time to lose if we want to learn our business without an even more costly "crash" programme.

Renewable resources

The effects of cold water on man's use of renewable resources is quite different from the effects on the exploitation of fuels and minerals. The biological cycles are very delicately dependent on water temperature, and therefore human activities that depend on parts of these cycles may change radically with small changes of the physical environment. The effect on life in Greenland of a few degrees change in water temperature, as already mentioned, is a case in point.

It has frequently been pointed out that the use of the biological resources of the world's water masses will pass through two stages. The first is the hunting stage, the stage of finding and catching, of exploiting what is already there. The second is that of culture and harvest, or farming. It is clear that on a world-wide basis our ability to use the ocean is still 10,000 years behind our ability to use the land; we are still in the hunting stage of development.

In the business of exploiting the sea by hunting, underwater activities are likely to continue to be restricted mainly to studies to give increased knowledge of the biology and behaviour of different species, and to research and development of improved means for finding and catching. Man has undertaken direct underwater fishing only for specific high value resources, such as pearls, coral, or some organisms valuable for pharmaceutical products. No resources of this type have yet been identified in cold water regions.

The culture and harvest of the biological resources of the oceans and inland waters will clearly be increased in the future, and there are those who say that the survival of the human race may depend on our ability to learn to farm the sea. We have made small starts at farming fish in fresh water and have had some success in managing nature by re-stocking lakes and rivers in a true cold-water environment; in the sea, oyster farming has been successful just to the edge of the cold water zone. Perhaps someone here will see a chance for a profitable man-managed concentration of cold-water invertebrates, or of kelp; but on the whole the possible returns from underwater farms in the cold-water zone would appear to be low in comparison with warmer parts of the world. We should not deceive ourselves: the average protein production per acre of sunlit sea, per year, is lower than the optimum production per acre of well-watered temperate land, it is even lower in cold waters and much lower when waters are ice-covered and shielded from the sun. But the methods of concentration of this rather sparse production may be very effective in cold waters compared to those in warmer areas. Some methods of concentration are physical, such as at the Antarctic convergence or on the Grand Banks, where the nutrients from a large part of the ocean are collected in a restricted zone or area. Some methods are biological, for animals successively higher in the food chain obtain their nourishment, in effect, from progressively larger volumes of the ocean; because of the comparatively simple marine communities in cold waters, the food chain is straightforward and may be more amenable to management than the more complex and variable food chains of lower latitudes. Thus it may be that some highly efficient cold-water food concentrators of limited distribution, such as the narwhal or the walrus, may be more easily and reliably farmed than their counterparts in warmer waters. Any such schemes will require a great deal more knowledge of the cold water environment and its inhabitants than we now possess. And we will not obtain that knowledge from the surface or the shore; we will have to enter the environment ourselves.

Hester has suggested that one of the most promising benefits of man's improving ability to work beneath the sea lies in the possibility of training sea mammals as work animals, and using them to run farms. We have all been intrigued by the way man and porpoise have learned to work together on various experiments in the past two decades. Could man, working beneath the sea himself, train killer whales to ride herd on "meat" whales? A whale can make first-grade red meat from the sea faster than a cow can produce beef. A baby blue whale doubles its birth weight in a week; it grows from two tons to twenty tons in six months and its body has a higher proportion of marketable meat than a cow. Many types of whales thrive in cold waters (although we must beware of jumping to the conclusion that they prefer it; almost all whales can live in any ocean, and perhaps they have gone to the cold regions to escape persecution.) Let us make sure that with our increasing ability in under-sea technology, we do not get too wedded to machinery and electronics. There may still be some things, like gathering honey and herding whales, that animals can do better.

One of man's truly great achievements, without which we might not be in this room today, took place about 20,000 years ago when he secured a whole new food source by making friends with some of the local wolves and getting them to help him, not to hunt the wild cattle as their instincts suggested, but to protect them and keep them to assure a steady food supply. And apparently man did this, not in the food-filled and complex jungle, but at the edge of the desert, where conditions were harsh but simple. Might not the harsh but comparatively simple cold northern waters be the place to start ranching sea mammals? We have no real reason to plead that we are less intelligent than our ancestors were when they began to train wolves to help keep cattle. Are we going to have to admit that we are less far-sighted and capable of restraint, and that we will just go on hunting until there are no useful sea mammals left?

Transport, Construction and Services

The problems connected with underwater operations related to transport and construction activities are almost all magnified by cold water and ice. For the most part these problems appear to be surmountable with present engineering skills and techniques. We know pretty well what could be done, given money and time, and what is not likely to be feasible. There are some critical lacks: we do not have a convenient reliable long-ranging way of determining position under water, nor a simple method of private or selective communication. We have only an imperfect idea of the cumulative consequences of human activities, such as the fallout of radioactive strontium or the year-round release of hot water from a power plant on the cold water environment. We have no good mathematical theory or engineering rule that allows us to translate movement of sea ice under natural conditions into stresses on vessels and fixed structures. A great deal of research development is still needed, of course, but for the most part, the pressing questions are not scientific or technical but what does it cost and is it worth it? These questions have social and political overtones, as well as financial and technological aspects, and the factors to be considered, even for cold water operations, can not be confined to the cold water

areas alone.

For example, the port of Montreal is still essentially idle for three months of the year, despite the success of a few pioneers in using it the year round. We are accustomed to this idleness, but the cost is enormous (just think of the consequences of closing New York or London for three months). We know that with present cold-water technology, given sufficient funds, a fairly steady stream of ships could be kept coming to Montreal during the winter. But would it be worth it? It would also be possible to build underwater port facilities and use cargo submarines throughout the year; it is easy to conclude that this would not be economically feasible for Montreal, even supposing the river channel were deep enough. But now suppose that Prudhoe Bay oil and Ungava iron were both to be shipped in quantity by submarine, because that was the most feasible method at the Arctic end; might not the picture change? Does it become important to Ungava Bay and to Montreal that Halifax already has submarine facilities?

Modification of climate

We have already noted that cold water masses, and differences in the temperature of water masses, can have an important effect on the climate, Man, being the meddlesome creature that he is, can't resist the urge to tamper with his climate. One way to do this is to push the oceans around. Any scheme to control the oceans so as to modify climate would have tremendous underwater ramifications. Some of these apply to cold water. You have all read of the proposals put forth by a group of enthusiastic Soviet engineers to dam the Bering Strait, and thus to modify the Arctic climate by manipulating the heat transfer between the North Pacific and the Arctic Oceans. Such a scheme is technologically feasible. I am not going to comment on whether it would have the desired climatic result, for that is not the subject of this conference; but any such scheme would require underwater activities in cold water on a scale thus far undreamed of. Think of what would be needed from the underwater industry in connection with the design, construction, operation and maintenance of such a dam, with its nuclear generators and gigantic ocean-size pumps; think of what we would need to study to determine the physical and biological consequences. There are other schemes for example that of just melting the sea ice all at once, on the theory that the present heat balance of the north is such that if the ice were removed from the Arctic Ocean it would not return of its own accord. Whether or not this is true is not a subject for this conference, but it is clear that before we can assess the feasibility or the consequences of such proposals, we must study the cold-water environment thoroughly in three dimensions.

On a smaller and perhaps more practical scale, there are undoubtedly going to be more and more requirements for underwater activities in connection with creating local "micro-climates" in cold water. A bubbler system around a lock or pier is an example of a micro-climate machine that needs underwater plumbers. At many Arctic communities in winter the nearest source of relative heat is the water beneath the ice in the nearby bay. Is it practical to think of an underwater heat pump, to warm and power the community? Nuclear reactors are already serving as power plants in Antarctica and are sure to become more widely used in cold climates. All the present types produce a great deal of excess heat which is usually discharged into nearby water, producing the modern phenomenon of thermal pollution. Could this heat be discharged into a properly designed harbour, keeping it open for docking submarines in winter, in the same way that the City of Edmonton inadvertently keeps the North Saskatchewan River open opposite the best hotels so that visitors won't think the winter is so cold? Could we have a fish farm in the warm water around the discharge point, raising species that could not live in the surrounding cold water and so would not stray, and which would be safe because the water was too warm for their predators? Or if one tried to do this, would one just end up with a giant artificially heated cesspool, with an increase of parasites and undesireable species? I am deliberately making suggestions which may be impractical or fanciful or downright foolish, but I want to provoke us all into the mood in which we feel that there are tremendous opportunities for exploiting our underwater environment, if we have the imagination to recognize them, the audacity to be original, and the knowledge to be realistic.

The damage that can be done

It has taken modern man a long time to learn, and to admit, what his ancestors knew: — that he is a part of Nature, and that all of his activities, whether he calls them natural or civilized or artificial, have an influence on the all-embracing ecosystem of which he is a part. Although the warning signs have been plain for some time, as a species we are just beginning to be frightened that we are threatening our own survival by our activities, and that the effects of our cutting the forests, stripping the soil, throwing wastes into the rivers and the air will lead to serious difficulties or perhaps disaster; not for our distant descendents but for our own children or even for us. We are not yet frightened enough to be willing to modify our destructive and wasteful short-term behaviour in order to achieve a productive and economical long-term prosperity, but a large part of our society is becoming worried, and is realizing that it is later than we had thought.

The effects of our short-sighted policies on the land and its rivers, and on the air, can be seen and smelled daily, and they are beginning to be felt in our pocketbooks; but most of us are still reluctant to believe that we can have much effect on the oceans. Despite the *Torrey Canyon* and a score of other serious oil spills, despite the ability of a chemical plant to ruin a Newfoundland fishery in a month, despite the tragedy that colonies of pelicans and gulls are dying out because the eggs are broken before they hatch as a result of the DDT in the fish that the parents eat, despite the fact that in two generations we have very nearly exterminated several species of the largest animals that ever lived, who roamed the world oceans and did not compete in any way with us, — despite these and many other examples, we still, as a people, persist in the wishful thinking that the oceans are too big for us to influence. Man is a curious and hypocritical creature; — he likes to boast that he is lord of the Earth, and that now he is about to conquer space, but he claims to be too puny and insignificant a creature to make the seas dirty all by himself. But the evidence is clear: we are beginning to manage the seas all right, and so far we are managing them badly. Before long, the term "high seas" may take on a new meaning.

Nowhere are the seas more vulnerable to the destructive effects of human activities than in the cold regions. The precarious existence of whole marine populations and the fragile links in the food chain in high latitudes, the remarkable sensitivity of a physical system in which a few degrees temperature change may make the difference between liquid and solid over immense areas, or may cause significant differences in chemical solubility, the susceptibility to a "chain reaction" process so that a single minor meteorological incident — e.g. whether the wind is northeast or northwest at the time of freeze-up — may affect the physical environmental and biological productivity for a whole year; — all of these show the extreme delicacy of the cold oceans as compared to those of warmer areas.

Unfortunately, we do not yet know enough to make a reliable prediction about the consequences of human activities, or human mistakes, in cold waters. Just now for example, the possibility of shipping large amounts of oil through the Canadian Arctic by supertanker or underwater pipeline is getting a lot of attention. If the northern seas become a major oil transport route, or if oil is produced from offshore wells in the winter, sooner or later there will be a large spill of crude oil into cold, probably ice-covered waters. What will be its effect? Will it behave much like an oil spill anywhere else, or differently? When oil is spilled on the water in warmer seas the film is broken up by wave action, the volatile constituents evaporate and the residue is altered by biological activity. What will happen in pack ice, where there is very little wave action, where low temperatures retard evaporation and chemical reactions and biological activity is much reduced? What happens when oil collects along the vital shoreline zone under conditions of little or no sunlight? Perhaps not very much; but we do not know enough to be sure.

There is an obvious and urgent need to find out enough about the nature and working processes of our cold oceans and lakes, at depth as well as on the surface, so that we can assess the consequences of human activities there in a knowledgeable manner. It is not only our moral duty to prevent waste and destruction of the physical and biological environment, it is in our selfish interest to prevent a waste of

time and investment funds, and to make sure that an emotional panic, based on lack of information, will not result in regulations or popular feeling that will interfere with the efficient and responsible development of our resources. Only with a thorough understanding can we develop plans for effective management of our underwater heritage; these plans cannot be purely operational, for they must include a firm solution to complex legal questions, and must have provision for regulation and policing. They also must face squarely the question of the ultimate ownership of the wealth of the seas and sea beds and the distribution of the profits from exploitation of that wealth.

The questions to be asked

A great many underwater operations which just a few years ago would have been dismissed as futuristic are now technically possible and reasonably safe. One might say that we are getting a grasp on the *"how"* of gathering information, moving materials, and working and living beneath cold or ice-covered waters.

The *"what for"* is also coming into focus. From many directions there are developments and problems that will require underwater research and operations. The possibility of finding and extracting fuel and mineral resources from beneath cold or ice-covered waters is becoming a probability, and the products will have to be transported. The need for management of the biological resources of northern and Antarctic seas is urgent, to conserve present stocks and to prevent spoiling the environment by pollution. There may be a possibility of increasing the productivity of selected biological resources useful to man.

In this conference we will probably talk mostly about *"how"* and *"what for"*. If, collectively, we can put a value on the *"what for"* and a cost on the *"how"* we should be able to assess the economic feasibility of underwater operations. Then we might be able to come a little closer to answering the pressing questions of *"when?"* and *"how much?"*

But there is another question which I hope will be asked at this meeting. That is *"by whom?"* Who is going to carry out all of this underwater activity I have been so glibly suggesting? This work requires highly trained, experienced people; where will they come from? With regard to the pure science of oceanography Canada has made a modest but respectable start; several Canadian universities have established enviable reputations for turning out oceanographers. But in the operational, design, and equipment field, where are we going to get the people? There is not one institution in the country that offers a course in ocean engineering or technical oceanology, and I do not know of any that have turned out, say, mechanical or hydraulics engineers who have had courses in oceanography. Perhaps the market is too small; but I suggest that we should give serious consideration to setting up in at least one Canadian institution an engineering degree course in oceanology, with special emphasis on cold water engineering. Here again is an opportunity for us to become world leaders by specializing in a subject which is important to us and uniquely ours.

I do not need to remind the delegates at this conference of how much there is still to be done. There are many aspects of our underwater environment about which we know so little that we are not sure whether what knowledge we do have is representative. Not long ago someone estimated that all the photographs of the deep sea floor ever taken, if added together, would show less than ten square miles of ocean bottom. This is our total permanent visual record of the surface of two thirds of our planet. Even major fundamental features may still be unknown or unsuspected; — think how recently it is that we have come to realize the extent and significance of mid-ocean ridges and fracture systems.

One fact, however, is clear, and is in part the reason for this conference. We cannot make a thorough study of the ocean unless we go there ourselves. I believe that it was the great oceanographer William Beebe who said that trying to study the ocean by means of things dangling from a boat was like trying to study wildlife and agriculture using a butterfly net let down from an aeroplane through thick clouds and fog. Despite the recent advances in remote sensing and sampling technique that statement is still largely true. Even the most brief visit to the underwater environment can broaden our understanding of it. Every diver experiences this. Every diver also knows how hard it is to explain this experience and broader understanding to those who have never been beneath the surface. Perhaps I may be permitted to illustrate this point with a personal experience. A few years ago I had my first look at the world beneath the unbroken bay ice in Antarctica. The world above the ice was familiar to me: barren volcanic rocks, snow, seals sleeping on the ice near tide cracks, with a few legs of brittle stars (starfishes) and fragments of dessicated algae and sea anemonae to suggest what kind of life might be present below. When I first went beneath the surface these suggestions seemed to be correct and adequate. In conformity with my preconceptions of the underwater world in Antarctica, all I saw at first were volcanic rocks, seals, brittle, stars, algae and a few anemonae. Then I found myself succumbing to the unearthly beauty of the world beneath the ice, and as I did so, the scientific questions began to crowd in. I became so aroused and excited by the drama and complexity of the Antarctic underwater landscape and its inhabitants that I came up from that first trip below the ice bubbling with unanswered questions about things that I already knew were there. I felt like a doctor who after trying to diagnose an illness by telephone was permitted to examine his patient for the first time. As for the seals; — I am not a biologist, but I thought I knew a bit about seals, for I had watched them and photographed them, hunted them and butchered them and eaten them, and had a layman's conventional knowledge of their behaviour. I knew that the seals would be fast and graceful under water, and that they made noises; but was still quite unprepared to find them such active, social, voluble, totally competent characters. I became convinced that for a person to draw conclusions about a marine mammal after knowing it only on the surface of the ocean is like a Martian trying to study the human race by taking samples from the jetliners that rise above the clouds; — the specimens are genuine, but they hardly tell the full story.

Why?

Perhaps we may consider one last question before we turn the conference over to the experts and their discussions of "what for?", "how?", and "by whom?". We might ask *"Why?"*. Why do we bother with underwater activities at all? Each of us here has his own answer, or collection of answers, to this question, and I have tried to touch on some of the elements of those answers this morning. For one thing, there is gradually emerging an economic justification; there is a growing opportunity to make money through activities involving underwater operations, although such activities are also very easy ways for one to lose one's shirt. There is also pure curiosity and the desire for knowledge, and in this field, today it is easy to justify this desire because the knowledge is needed for many practical and policy reasons. But most of us will admit, if we are honest, that over and above all these reasons yet including them, there is the fascination that the marine environment has for most of mankind. There are easier ways of making a buck; there are certainly many other rewarding and more comfortable fields of research; — so why are we all here today? Is it something in our blood?

A generation ago biologists were fond of comparing the composition of our blood and cell matter to that of sea water, and by noting subtle chemical differences between us and the present seas, making estimates of how long it had been since we — life on Earth — had first developed in the ancestral ocean. Today we can point out fallacies in this kind of reasoning, but the instinct that connects us to the sea is still with us strongly. Bernal has shown that it is probable that organic organisms developed, not in the sea as such, but by the action of sunlight on the surface of the scum that collects on the beach at the edge of the ocean. That was maybe 4,000 million years ago. If you look on any beach on a sunny summer afternoon, you will note that we have not moved very far in four billion years. Is it just our ancient and proper instinct — older than man, and as old as life itself — that draws us back to the sea?

Geophysical exploration methods for use in cold or ice-covered waters

by Norman R. Paterson*

As I frequently point out to the marine scientists, the geophysical industry has been operating on ice-covered water ever since the commencement of geophysical exploration. In Canada, Russia and Scandinavia a great deal of the mineral exploration work has been done on inland lakes and rivers, which all of you know are frozen in these countries anywhere from 2 to 12 months of the year. The methods we have used are mainly minor modifications of those employed on the adjacent land area; airborne methods, with a few exceptions, are equally effective on frozen lakes as on land. Petroleum exploration has also had to contend with cold and ice-covered water in its northern operations, but the nature of sedimentary basins is such that water tends to form a smaller proportion of the total area than in most mining districts. Petroleum geophysical techniques have been applied effectively on ice on the Mackenzie River and in Great Slave Lake.

The sea, and particularly the polar sea, is another problem again. The geophysicist has to cope with factors such as:

— much larger distances;

— remote areas without convenient logistic support;

— extreme weather conditions (including "white out", high winds and wave action);

— moving ice, large ice thickness and severe vertical ice movement;

— difficult transportation in many ice areas;

— lack of available hydrographic and geologic information on which to base an exploration program;

— and last but not least, the problem of high water conductivity.

My first experience with geophysical exploration in the ice-covered polar regions was an experimental hydrographic survey carried out on behalf of the Geological Survey of Canada in the winter of 1958-1959. A single-channel hammer seismograph was being used to sound through the sea ice in Resolute Bay in an attempt to improve on the early methods of echo sounding through ice. Our geophysicist in this instance was a Pakistani named Abul Mousaf. His team included a German-born technician and a local Eskimo with dogteam. Their work site was some distance from Resolute, at a place where water was several thousand feet deep. Darkness closed early at that time of the year, but Abul paid little attention to the efforts of his Eskimo guide to get him to put his equipment away and return to camp. The Eskimo grew more and more agitated and pointed excitedly into the approaching darkness. Finally, he seized the equipment, put it on the sled and headed for Resolute, with Abul barely able to jump aboard. That night, the Eskimo apparently returned to his village and described to his friends the courageous action of the scientist from Pakistan who pursued his experiments fearlessly while a polar bear circled the site, only 100 feet away.

Since that time, ice sounding methods have been improved; new techniques of gravity meter surveying have been introduced; a variety of seismic methods have been applied, both on water and on ice; magnetometer survey methods have been used extensively on water, on ice and in the air; a helicopter-borne hydrographic technique has been perfected; airborne radar techniques have been employed to sound ice and snow thickness; magnetotelluric experiments have been carried out by the Dominion Observatory; conventional mining geophysical methods have been used on Baffin Island, Victoria Island, and other southern Arctic areas with varying degrees of success. Much of this work has been and still is experimental, and some serious problem areas still exist. One of these is the problem of doing seismic surveys effectively on ice. Experiments this winter in the Arctic using various types of seismic sources are understood to have met with only moderate success. The industry is grateful to the Polar Shelf project of the Department of Energy, Mines and Resources for their pioneering work in this field, and their excellent cooperation with the commercial organizations involved in the area.

The subject of underwater mining and mining exploration is covered at some length in a paper entitled "Underwater Mining: New Realms for Exploration" that I delivered at the Prospectors and Developers convention in Toronto in 1967, and which was published in the Canadian Mining Journal in April of that year. The paper deals mainly with exploration on the continental shelves, and points out some of the advantages of the marine environment in geophysical exploration as a whole. Included in these are:

— easier access and mobility;

— simplicity of geophysical surveying through improved coupling with the ground and the uniformity of the ground medium;

— the ability to use the third dimension (elevation) to increase the value of the geophysical measurements; and

— the possibility that bottom sampling and drilling techniques may in fact be cheaper before long on water than they are on land.

It is also pointed out that electrical methods used for mining exploration on fresh water, are of restricted use because of the high water conductivity. On the other hand, such techniques as the continuous seismic profiling method is greatly more effective and much less expensive. Marine seismic methods indeed are as little as one-tenth as expensive on water as they are on land, and in most cases much more effective. They are also more rapid, which is an important factor in northern exploration, where the useful season may be as little as one or two months.

On ice, some of the above advantages disappear, and other disadvantages are introduced. Access, for example, may or may not be easy. It is not always possible for tracked vehicles to cross the sea ice, particularly in the inter-island areas. Ice movement makes navigation very difficult, as the survey position is constantly moving. Helicopter transportation is rapid, and certainly simpler than in heavily treed land areas; but helicopters require navigational aids and large fuel supplies, that greatly increase the cost of operating. Coupling with the water is difficult through ice cover, and the mobility that is possible with geophysical surveying on water is lost. Seismic surveys have been done effectively with the geophones on ice and the charges lowered through the ice into the water. However, results are extremely bad if the ice is broken or rafted, or if a small air gap is present at the base of the ice layer. Almost continual ice movement reduces the effectiveness of both the seismic and gravity techniques. Marine bottom sampling and drilling techniques are no longer effective, and equipment for such operations is difficult to transport and set up on sea ice. The third dimension is still available to the geophysicist, and I think will be exploited increasingly in future survey work. Vertical gradient measurements are of particular interest in gravity and magnetic work in trying to resolve physical property changes in a vertical direction. Normally these have to be determined analytically,

*Consulting geophysicist, Toronto

by taking measurements in two directions on a flat surface. Through the ice they can be determined directly. In seismics with vertical source or receiver arrays can be used to improve signal to noise ratio.

The problems of operating in the Arctic are formidable, but are slowly being studied and solved, notably by government agencies such as the Polar Shelf project. Conferences such as this will improve communication between the various disciplines engaged in Arctic work, and hopefully will encourage the dissemination of useful information in the form of published reports and scientific data.

GEOLOGICAL

Dr. J. I. Marlowe*

The main problem confronting the marine geologist is that of obtaining information on the geological nature of the sea floor and the sub-bottom. This task is made difficult to varying degrees by factors associated with, firstly, the fact that there is usually a great distance between the geologist and his target; secondly, the geologist is usually unable to see his target; and thirdly, he is usually unable to control precisely the location of his sample sites. Most of the present technology allows the marine geologist to make only indirect evaluations of geological situations. The problems and techniques of marine geological operations in cold waters are essentially those pertinent to those same operations in warmer waters. An obvious exception to this generality is the frozen sea environment, which we will treat separately here. The techniques used by the marine geologist to obtain information in the field can be divided into three very general categories. These are:

1. The spot sampling techniques that involve the collection of geological samples at isolated locations, with the subsequent interpolation of parameters between these locations.

2. The continuous observation techniques, which allow the recording or observation of properties of the bottom or sub-bottom along traverses across the bottom. With this technique, spot sampling is usually necessary as a co-technique in order to provide control information.

3. The techniques that allow direct observation or measurement of the environment by the geologist.

The first category, spot sampling, is probably the oldest, most widely used and most varied in its application. These methods utilize a wide variety of sampling tools, ranging in complexity from sounding leads with hollowed-out ends to highly instrumented devices that are capable of taking large, undisturbed, oriented samples from the deep sea floor. The basic purpose of all of these tools is to recover representative samples of the sea bottom at the point of contact. Sample programs based on data collected by all of these tools, however, are subject to errors inherent in the method, which amounts, in essence, to a blind groping towards the bottom from a moving platform located at a point which is vertically remote from the target. Tools used in spot sampling programs are divisible broadly into four categories. These are: the clam-shell or snapper samplers, the corers, the drills and dredges.

The clam-shell, or snapper or grab samplers, as they are variously called, vary widely in both their design and capacity to obtain representative samples. Basically, all of them cut or scoop samples from the upper few centimeters of the bottom sediment. Many of them are more efficient in some types of bottom than in others. The size of sample that can be obtained by these samplers can be extremely critical to the assessment of bottom type. Generally, the larger the sample obtained by this blind grab method, the more dependable is the determination of bottom quality at that point. Many of these samplers are small and light enough to be easily portable and so can be used from small boats or from improvised lifting rigs.

Corers vary in design to a lesser extent but have in common the facility of obtaining samples representative of vertical variations in the bottom sediment. The length of core and hence the length of the geological record obtained is governed by the length of the core barrel that can be attached to the coring tool and by the ability of the equipment to penetrate bottom sediment. Mechanical factors inherent in coring tool designs often adversely affect the quality of the core sample through distortion or impaction or separation of the core. Core samplers in general have an advantage over the snapper samplers, in that they obtain material representative of temporal variations in the character of the bottom which the geologist may then relate to geological events. The major disadvantages of most coring equipment lie in their relative difficulty of handling. Large corers in particular require special lifting equipment and a spacious work area on deck. Careful design and layout of deck machinery and rig are important to the efficient and safe handling of large corers. I believe that much of the tedious and difficult work associated with rigging and unrigging corers could be perhaps eliminated by utilizing ideas on equipment design borrowed from the drilling industry.

The problem of obtaining information on vertical variations in the properties of very hard or rocky bottom is being met by several underwater drills which operate at the end of umbilical lines attached to the mother ship. These devices are capable of obtaining core samples up to several feet in length in hard rock. It is expected that one or more of these drills will soon appear on the commercial market. Deep drilling equipment is being covered elsewhere in this symposium and I offer no comment on it here.

Dredging is essentially a spot sampling technique, although the dredging operation normally covers a wider area of the bottom. Because of this wider coverage sampling by dredging often has a better chance of success than have the one-shot techniques such as snapper, corer and drilling methods. Dredging is a brute force technique and it requires comparatively heavy gear. Where the bottom is composed of gravel or rock ledges or loose detritus from outcrops, the dredge is often the most reliable tool. The disadvantages associated with dredging include the need for relatively heavy handling equipment, heavy winches and heavy wire.

The evaluation of data obtained by all of these techniques is affected adversely by the fact that the samples recovered may not accurately represent conditions over inter-sample areas of the bottom. I think every marine geologist has on some occasion been disconcerted by disparities between samples which were supposedly taken at identical locations and, similarly, most have at some time been impressed by the difference between samples obtained and the actual nature of the bottom, where this could be determined by other methods.

The second main category of techniques is that which provides continuous observations or records on traverses along the bottom. This includes the use of recording echo-sounders, side scanning sonars, underwater cameras and underwater television systems. Continuous-reflection seismic devices also come under this category and have been adequately covered already. Echo-sounding records have been used for many years to distinguish among bottom types and to provide data on the shallow sub-bottom. This technique is essentially an extrapolation technique and must be used in conjunction with a sampling program in order to relate differences in bottom type to differences in the quality of echo-sounder records. When used with careful control by sampling, this method affords a rapid, inexpensive and reliable reconnaissance of large areas. Depending upon the type of equipment used, the method is limited by the depth of water in which it is operating. Conventional, navigational echo-sounders operating at around 14 kiloherz in waters at less than approximately 180 meters in depth can produce echoes from as deep as 4—6 meters below the bottom, again depending upon the bottom quality. The record produced is dependent upon continuous soundings and therefore is not presently usable in ice-covered waters.

Side scanning sonar is coming into increasingly wide use as a geological tool. This technique involves a projection of

* Marine geologist, Bedford Institute

acoustical energy obliquely onto the bottom rather than vertically, as in the conventional echo-sounder. This produces an echogram which represents structures and surface textures on the bottom according to their acoustical relief and their relative absorbtive qualities. Such a record provides a coverage over an area of bottom at some distance from the energy source and it is presented in graphic form as an oblique "photograph" of the bottom. Again, the use of this method in geology depends very strongly on sampling control in order to determine just what variations in the graphic record may mean in terms of actual bottom.

Underwater camera and television equipment allows the geologist to examine the bottom visually and can provide information which is not available through other methods which have thus far been discussed, such as lateral relations between sediment types and the relative importance of such features as erratic boulders. Television is considerably more versatile in this respect than is the camera, as it allows the evaluation of the nature of the bottom while a survey is in progress and the angle of view or track over the bottom can be altered to suit the observer. Furthermore, continuous information is provided by the television whereas most camera systems operate on a fixed time interval. Both methods can produce permanent photographic records. These techniques can be very usable in determining details of variation in the bottom and are usually brought into play after preliminary ideas as to the geological nature of an area are arrived at.

The third major category of techniques, and perhaps the currently most exciting one, includes methods which provide direct on-site inspection of marine geological features by the geologist. The oldest of these and the most widely used is diving with the aid of underwater breathing equipment. The uses and applications of this type of device are fairly well-known. They have allowed the geologist to work in personal contact with the bottom geology in depths of approximately 200 feet or less and have enabled a close study of many features in the near-shore environment which were previously inaccessible. The development of the deep-diving research submersible, however, for the first time allows the geologist directly and selectively to observe, to measure and to sample features on the bottom in full context of their surroundings. For the first time, the geologist is able to make a true field evaluation of such features. Potential for the development of this aspect of marine geological exploration would appear to be very great.

The foregoing discussion of basic approaches to the acquisition of marine geological data has covered techniques used on floating platforms in navigable waters. What has not been considered are the problems associated with carrying out geological work in areas where all or of the sea surface is frozen. What then such studies carried on from the sea ice where problems of transporting equipment, large quantities of supplies and providing power to run machinery becomes monumental? I think the answer to that is that to date nearly all geological programs in frozen sea areas have been rather modest ones.

Limits on the quantity and weight of equipment are largely dictated by the capabilities of the transport facilities that are available. Light, portable sampling equipment has been used in many aircraft-transported marine geological surveys in the Canadian Arctic to provide reconnaissance on the bottom, and in some cases, the upper few feet of sub-bottom. Samples were obtained either through holes drilled in the ice or through available natural holes. The data from these surveys were all based on spot sample techniques.

The serious disadvantage of carrying out geological work in frozen sea areas lies in the present lack of a capability to obtain echo-sounding records along continuous traverses. Although echo-soundings can be obtained through the ice at point locations, there is at present no means of obtaining continuous echograms from the surface. Such records, if they were available, would considerably enhance the interpolations now being made on the basis of spot samples alone.

DRILLING IN ICE-INFESTED WATERS

by Dr. G. H. Jones*

This discussion is concentrated principally on areas of sea-ice. From the point-of-view of drilling in ice-infested waters, we may consider three main categories of environmental conditions.

1) Areas with appreciable periods of ice-free conditions.

2) Areas with stable ice present for appreciable periods.

3) Areas almost always covered by moving ice.

Some areas may fall in both categories 1) and 2). We shall consider each of these three environmental conditions in turn.

Areas with appreciable periods of ice-free conditions

This is the only ice-infested environment in which the drilling industry has any significant experience. Drilling within such an environment may be considered in two categories as different techniques are required. These are the exploration stage and the later development stage. Up to now, almost all experience has been in Cook Inlet, Alaska.

Exploration Drilling

This has been carried out by "hit-and-run" methods using mobile rigs during the open season. Such rigs retreat to southerly areas where they can continue drilling during the northern ice season. Most such exploration drilling has been carried out by relatively fast, self-propelled, ship-shaped drilling vessels or by ship-shaped barges, which can be towed at higher speeds than semi-submersible and jack-up type rigs. A lesser amount of drilling in Cook Inlet has been by rigs of limited mobility which can be dismantled and stored onshore during the winter. Our company has used both self-propelled and towed floating rigs for several seasons in Cook Inlet. Such drilling does not differ greatly from drilling elsewhere with the exception of the uncertainty as to the date of the beginning and end of each season and care has to be taken so as not to be caught by the onset of dangerous ice conditions. There are other areas in which a Cook Inlet-type of approach to exploration drilling could be undertaken. These include the Grand Banks, the Gulf of St. Lawrence, Labrador coastal waters, Hudson Bay, and possibly parts of the High Arctic, as well as Scandinavian and Russian waters. In less remote areas, it may be feasible to use less mobile drilling vessels than those required in more distant areas or in areas with a very short open-water drilling season. As distances from southern work areas increase and as the open-water season decreases, then mobilization costs become large in proportion to costs during drilling operations and may become prohibitive except where exploration possibilities are above average. As ice conditions become less predictable or more severe, then costs and particularly those of insurance will escalate considerably and may greatly influence the economics of drilling. In certain areas, drilling will be influenced by ice conditions in bottlenecks along the approach areas to locations. Among such potential bottlenecks are the Point Barrow area of northern Alaska, where the icepack impinges upon the Point, and may only allow a navigation season of six weeks, thus restricting access to the Beaufort Sea-Mackenzie Delta area, which may have a three-month open-water season. Similarly, the Hudson Bay area enjoys a longer season free of heavy ice than the Hudson Strait approach to the Bay. In areas with short open-water seasons, alternatives to the "hit-and-run" drilling method must be considered. It may prove feasible to freeze in a vessel during the winter so as to gain valuable time at the beginning and end of the season, even at the cost of loss of remunerative operations over much of the year. Where freezing-in is not specifically

*Canadian Manager, Global Marine Drilling Company

desired, it must always be considered as an emergency possibility due to an early onset of ice conditions.

Development Drilling

In areas where exploration drilling has been carried out by the above techniques, development drilling has been undertaken from specially designed bottom-mounted platforms capable of standing up to harsh winter conditions. This has been achieved by "brute-strength" supplemented by additional protective devices. This "brute-strength" platform method of drilling has been effectively undertaken in Cook Inlet where 14 permanent platforms are installed. Although these massive structures have proven technically successful and able to cope with difficult environmental conditions on a year-round basis, their economic success may be questionable in some instances. Such costly structures can only be justified where reservoir conditions permit high sustained petroleum production rates. Permanent Cook Inlet platforms have been designed to cope with sustained winds of 60 mph with gusts to 100 mph, as well as with tide variations of 33 feet, with storm waves of 28 feet, and with currents of six or more knots. These conditions are accompanied during part of the year by ice floes of six feet thickness and by ice-bodies of up to 1,500 tons, together with atmospheric temperatures down to minus 40 degrees F. and water temperatures as low as 20 degrees F. Cook Inlet platforms commonly have one to four massive legs made of special alloy steels up to two inches in thickness. These structures, from each of which some 32 to 48 wells are commonly drilled, weigh from 3,000 to 5,000 tons and may sustain loads of up to 3,000 tons of oilfield equipment. Such platforms have initial costs of $5 to $10 million with insurance costs 50 percent higher than normal and with additional high costs per well.

Cook Inlet tides and currents are severe, but ice conditions are not of the same degree of severity as in the High Arctic, neither are water depths as great as are those of many Arctic areas. Whereas ice-bodies in Cook Inlet rarely reach more than a thousand tons, those in the High Arctic may be measured in millions of tons.

As exploration moves into areas of heavier ice, particularly into deeper water, there will be a limit to the normally successful utilization of massive platforms. In addition to sheer structural strength, it is probable that supplementary devices will be developed to minimize the detrimental effects of heavy ice and to reduce the structural strengthening necessary to cope with increasingly severe conditions. Although some experience has been developed with protective devices, we are now moving from proven engineering experience into an area of conjecture. One can envisage devices designed to present a more streamlined frontal face toward oncoming ice masses than the present cylindrical platform legs, but, since ice is liable to come from different directions, the streamlining may be developed with a rotating mechanism. Such a device might have a rotating Alexbow or some other prow shape. Such structural modifications might further be accompanied by other devices, such as ultrasonic waves, laser beams or bubbler systems. In Cook Inlet, it has already proven necessary to protect some platform legs by adding steel legwraps to protect against the abrading action of flowing ice. Development of such wraps on an expendable basis might have merit. Such devices should enable permanent platforms to be emplaced in locations with ice conditions more severe than in Cook Inlet, but with increasing cost penalties. It will not be possible to proceed too far before it becomes economically untenable to further increase weight and strength of structures. In many Arctic areas, it may be feasible to undertake the exploration phase of drilling by semi-conventional means from slightly strengthened floating vessels but it is difficult to foresee that development drilling and production can be satisfactorily undertaken from surface platforms resting on the ocean floor.

In areas where surface-based development drilling and completions are not technically or economically feasible, surface completions may be possible either on the ocean bottom or on structures raised above the bottom, beneath the base of floating ice. Although subsurface completions have been undertaken in southerly areas, there would be special problems in ice-infested areas since tankers would not be able to load from underwater storage during part of the year and pipelines to shore would encounter hazards where the pipes reached the shoreline and would be subject to attack by moving ice. In Cook Inlet, pipelines leading from fixed platforms to the shore have been damaged by the effects of ice and currents. Nevertheless, many problems can be overcome where economic incentives are sufficiently great.

In the main moving pack of the Arctic Ocean ice conditions may be too severe for any man-made steel platform to resist, but it may prove possible, particularly in shallow water, to develop artificial islands comparable with those of THUMS Project offshore of Long Beach, California. Another possible approach to deeper water would involve taking advantage of natural ice islands, some of which may have thicknesses measured in hundreds of feet and to install such islands in convenient locations with whatever artificial modifications are necessary to ensure preservation at given locations. An experiment along these lines is in progress offshore of the north slope of Alaska where oil interests are experimenting with artificial thickening of small ice islands which might offer potential as docking facilities for deep draft tankers.

Areas with stable ice present for appreciable periods

It appears that in certain High Arctic areas it may be advantageous to determine if the presence of ice can be turned to the benefit of the driller. Open-water may be present for periods up to a few weeks or it may not be present for many years, but, in some areas of permanent or nearly permanent ice, much of the sea-ice appears to be essentially stable and remains land-fast for extended periods. Our company and others have initiated research into the characteristics of the ice to determine whether it may be feasible to use this apparent stability of the ice to provide a safe platform for drilling within certain offshore areas. Attention is being directed to the land-fast ice to determine quantitatively the following factors considered to be of significance for drilling.

Stability of Ice

How stable is ice? For how many months can ice in a specific area be trusted to remain safely land-fast? How does land-fast ice behave under the influence of tides, currents and major storms? If the ice moves, how fast does it move and over what time period? Are such movements predictable? If advantage is to be taken of stability of the ice, it will be normally necessary for the platform on or in the ice not to move for more than ten percent of the water depth in which the rig is drilling. The answers to these questions are the subject of detailed research and it is hoped soon to find accurate answers to these questions.

Ice Characteristics

What are the characteristics of ice, which may affect its use as a drilling platform? Does it have the strength to stand the static loading of a heavy rig and of auxiliary facilities? Can it stand the dynamic loading and other physical strains of drilling activities? Under what circumstances is sea-ice subject to creep or to fracture as a result of the presence of an active drilling rig? Related to these questions are further questions concerning the homogeneity of the sea-ice and the thickness necessary to sustain given activities. If a certain ice thickness is needed for specific activities, then it must be determined under what circumstances and for what period and with what predictability it is feasible to depend on ice of required characteristics in the given area. If naturally occurring ice of such characteristics is not present for a sufficient period to sustain the desired activity, then questions arise as to how the ice can be artificially strengthened so as to fit economically within the context of logistic feasibility in a remote area. Alternatively, is it preferable to take advantage of the stability of location of the ice but not to use it as a platform and to set some type of floating vessel within the ice rather than on it? Even should it be desired to place the drilling rig on the ice, is it necessary for safety to provide flotation to cope with emergencies? These problems are under active review by two research teams from our company and some of these questions are the subject of research by others. As yet, very little relevant experience has been attained in this field of research, although isolated raw data with bearing on specific problems has been accumulated. A limited amount of operational experience has been achieved by the mining and petroleum industries with drilling on ice-covered lakes, but conditions in these smaller bodies of fresh rather than salt water are different in several respects from

those within the land-fast sea-ice of the Arctic.

Related Environmental Conditions

In addition to these factors of ice stability of position and strength under given stresses, there are other factors which can have a profound effect upon the technical and economic success of any potential offshore drilling operation in land-fast ice areas. Many conditions are not unique to offshore areas, but are shared by onshore High Arctic areas. Nevertheless, the severity and potentially significant effects of atmospheric conditions are increased in the offshore environment, so that white-out, fog and superstructure icing will profoundly affect drilling operations, and also supply by air and surface methods.

If it is assumed that ways can be found to carry out successful exploration drilling, then we will be faced with development drilling and subsequent production operations. Bottom and near-surface completions with related pipelining will certainly pose problems in areas of stable ice-cover. It is not feasible to give definite answers as to the economics of drilling and petroleum production in areas of land-fast ice, but it appears that answers can and will be found to the various problems posed, provided that the economic objectives give the incentive to persevere in their solutions.

Areas almost always covered by moving ice

In addition to the above two environments there is a third major condition which prevails in the Arctic Ocean. Recently some companies have filed on Petroleum & Natural Gas Permits in areas of constantly moving icepack and some Permits embrace very deep water. Arctic icepack may move several miles per day. Due to the almost immeasurable forces within the icepack of the Arctic Ocean, we tentatively conclude that man-made surface structures in fixed locations do not appear to be feasible within the foreseeable future, except under conditions of shallow water.

Given this situation, the potential driller is free to use his imagination as he foresees the development of drilling systems which are presently at or beyond the margin of mans' technical ability. In these days of advanced technology, there are few ultimate limitations to what man can achieve, but whether an effective drilling and oil production system can be set up in deep waters beneath moving Arctic icepack on an economically feasible basis remains extremely conjectural. A drilling system with the use of underwater nuclear-powered drilling rigs and nuclear submarine tenders or of other sophisticated expensive devices may prove practical, but a decade may be required for its development for industry use. Whether such devices are developed and at what speed depends largely upon world market conditions and upon petroleum developments in more accessible Arctic areas. Should geological opinion favour the presence of multi-billion barrel oil fields with favourable conditions of producibility within areas of moving icepack, then there will be sufficient incentive to develop the means of handling these extremely adverse environmental conditions, but anything short of outstandingly favourable geological conditions would preclude these areas from development within the foreseeable future.

In summary, the greatest prospects for important economic development of petroleum within ice-infested waters depend largely on the development of a highly flexible series of inter-related drilling systems. Such systems will have to cope with a variety of different environments so that a given drilling rig will be able to drill during most of the year, even although a given environmental condition may only prevail for a short period. The high costs of the ice-infested environment will put a premium upon drilling systems adaptable to work in water, from stable ice and on land. Drilling programs may have to be of sufficient magnitude so that many rigs can operate simultaneously so that the logistic support facilities, including large helicopters capable of operating during the Arctic winter darkness, and other expensive devices can be sustained with sufficient workload to justify their expense.

Finally, as an appendage to this discussion, mention should be made of areas in which ice is largely in the form of icebergs. Such areas include Baffin Bay, Labrador coastal waters and the Grand Banks, as well as the easterly portio[illegible] the Arctic Archipelago. Research into [illegible] effects of such icebergs on potential drilling and producing operations has included a statistical study of iceberg tracks over a long period. In some areas the probability of interference to an operation at a specific location by an iceberg may be no greater than the possibility that the eye of a tornado will strike a given drilling rig in the Gulf of Mexico. In such areas, it may be technically and economically feasible to proceed with routine drilling operations, whereas in other areas hazards may be much greater. In these latter areas, plans must be made for measures to take effect if an iceberg should approach an operation. It would be important to have an accurate tracking system which could forewarn operators of danger with sufficient time lapse to enable protective measures to be taken. With a floating drilling vessel undertaking exploratory operations, it should be feasible to remove the rig after sufficient warning, although false alarms would prove expensive. Where icebergs reaching the bottom or near-bottom of the ocean are involved, a considerable hazard to drilling or production facilities would be present and it is of importance to investigate possibilities of diverting icebergs away from such facilities. Small ice islands and large tabular icebergs have been moved successfully by pushing by ships. With irregular, unstable pinnacle-type icebergs subject to sudden catastrophic overturning, other methods must be devised to achieve success in re-routing them. Destruction of icebergs by non-nuclear devices offers little promise, but ways of changing the iceberg tracks may be found, provided sufficient forewarning of their track is forthcoming. Sophisticated side-looking radar and other surveillance systems will be necessary.

In summary, man has begun to develop methods of coping with drilling under the less severe conditions of the ice-infested offshore environment and there are good prospects that, within five to ten years, he will enter areas with more severe conditions. Difficult conditions associated with constantly moving surface ice and deep water may not be overcome so soon, unless extraordinarily great economic prospects are present.

RECOVERY — T. F. L. Method

by P. Ory*

Mr. Chairman, Ladies and Gentlemen:
I am pleased to present today a brief exposure of what our company, ELF-ERAP, has been doing since 1962, on some particular points.

Up to now Exploration and Development of marine oil fields in shallow waters have been done exclusively with fixed multiple well platforms and the wells were mostly directional.

In such a case, a large diameter conductor pipe, embedded in the sea-bed, bears, at the platform level the Christmas tree. Flow lines connect the fixed platform to the central platform where are the production facilities (treatment and so on).

Now, some of these installations exist in 300 ft. of water. However, Oil Companies are now exploring the Continental Shelf. In depths ranging from 600 to 900 feet and over (ex. Santa Barbara Channel). The increasing depth and often the severe meteorological conditions considerably increase the cost and the difficulties of building fixed structures.

These considerations have led many

*Chief Engineer, Drilling & Production, Elf Oil Exploration & Production

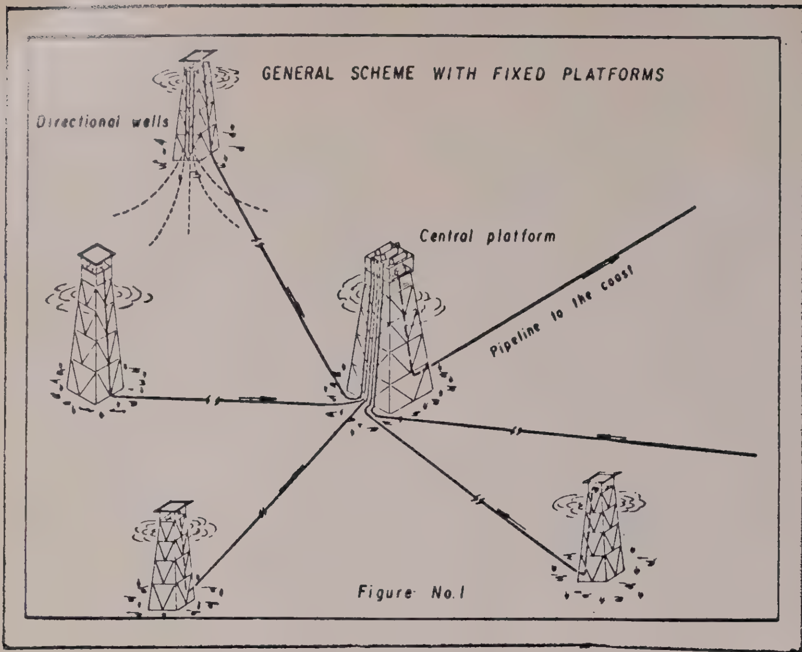


Figure No. 1

oil companies to use different techniques for drilling (floating vessels, semi-submersibles) that all of you know.

For the drilling process, we can say that the problem has been satisfactorily solved up to 1500 feet.

Production experimentation is much more limited for these deep wells.

One of the first methods, used on the U.S.A. West coast, the wells after being drilled, were equipped with almost standard Christmas trees with a minimum of adaptation to the marine site. Small floating ships ensure the maintenance of the well (wire line jobs etc.)

This method presents some large inconveniences due to:

1) High cost of the maintenance ships
2) Necessary assistance of divers and we know that the increase of water depth decreases considerably their working time. They are now almost limited to 600 feet.
3) High waves or local storms which can prohibit or stop an urgent intervention.

To reduce the costs, to be able to get rid of the meteorological and oceanographic conditions (waves, currents, water depth) the T.F.L. Method was invented by Shell.

T.F.L. method principle

Six right satellite underwater wells, or more, are connected to a large platform, either fixed or articulated, by hydraulic or electric lines for remote control and by flow lines.

For the control operations, maintenance and well bottom equipment, the T.F.L. Method replaces the standard wire line tools by special tools with knuckle joints pumped through the flow-line with crude. These tools are pumped from the platform through the flow line, down to the tubings and back up again.

To fulfill these conditions, the set-up includes the following particularities:

— Each well is completed with two tubings with special down-hole equipment, such as circulation nipple, anchoring nipple for storm choke etc.

— The Christmas tree is made up of two master valves for each tubing and one swab valve, and a wing valve. The two tubings are connected to two and three-eighth inch flow-lines without discontinuity for the inside diameter. A diverter tool plugs off the vertical outlet of the swab valve, and guides the tools pumped off from the tubings towards the flow-lines.

The minimum radius curve is 5 feet. The pumping equipment necessary for the tool propulsion would seem to limit the distance between the well and the platform to 9000 feet.

The production and control equipment listed below will equip the platform.

For such well:

A valve manifold with the special connections for the tool introduction.

A remote control unit for the Christmas tree valves.

For all the wells connected to the platform:

A common separator and storage unit.

A high pressure pump.

T.F.L. tools

The means I have just listed enable us to install, use and recover the tools generally used on land production.

STORM CHOKES, TUBING PLUGS, BOTTOM HOLE PRESSURE BOMBS, PARAFFIN SCRAPERS.

Different tools are available. The first ones we tried were designed by Shell. Now we are using Otis tools and some tools designed by our own engineers.

CONCLUSIONS:

French Oil Companies have been conducting tests on this method for the last five years. —

— on a dry hole

— on a productive well on land

— on a producing offshore well off the coast of Africa in 100 feet of water.

This last well has been producing without any interruption for 9 months, on a daily rate of 4,000 barrels per day.

This method can also be used offshore for deep underwater wells. The daily productivity of the well, the length of flowlines and tubing will determine the choice of the inside diameter of the flow lines.

Up to now only two and three-eighth inch tools have been studied. We have yet to work on larger diameter tools.

The costs of drilling and completing a well underwater are high. The maintenance operating costs will be a little

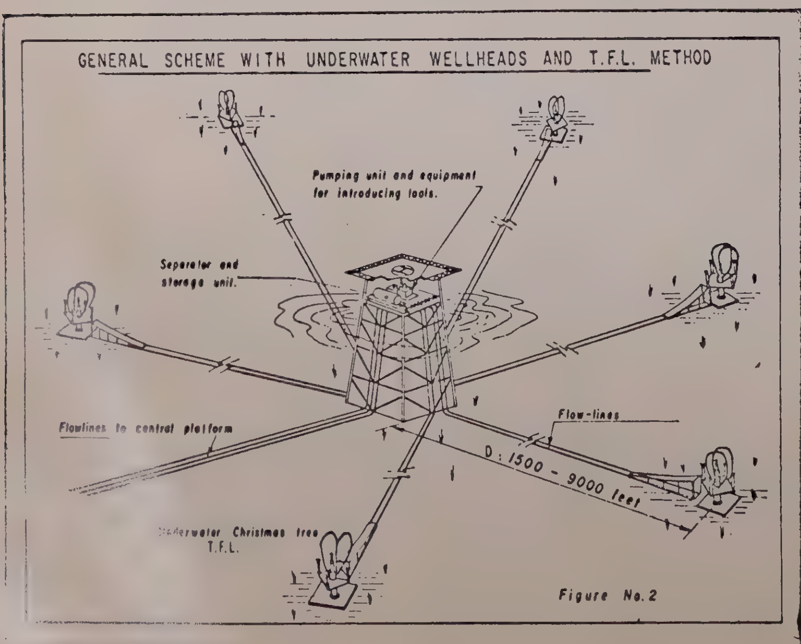
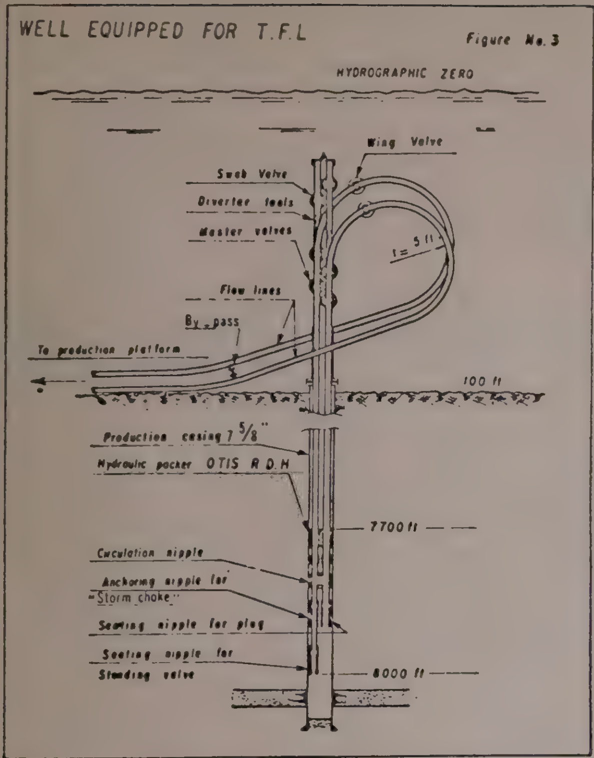
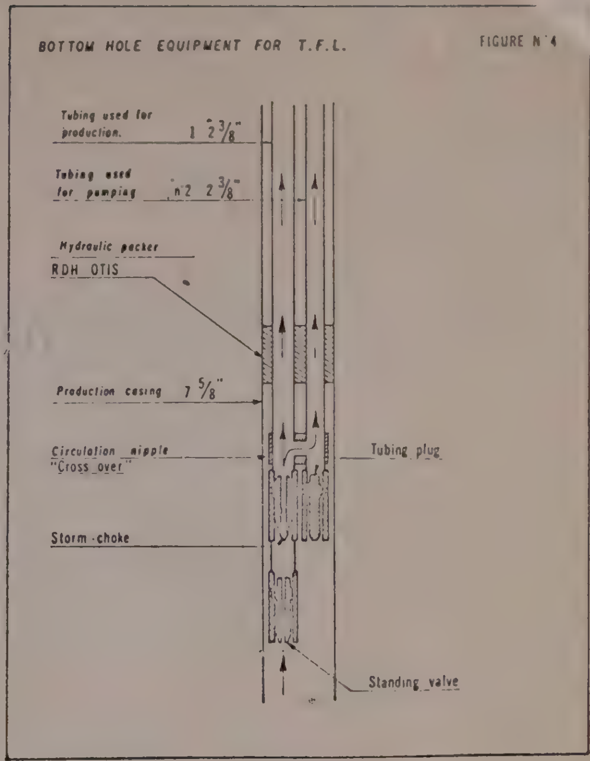


Figure No. 2





higher than now. Therefore we have to find some big producers.

Articulated platform

Even if the different types of mobile drilling units (jack-ups, vessels, semi-submersibles) are diversified enough to solve Offshore drilling problems, we are still faced with the problems of development.

The cost of the fixed platform greatly increases with the water depth.

These lattice structures embedded into the sea floor must withstand very rough weather conditions and their tonnage increases almost in proportion to the water depth. Therefore, the construction and setting of such platforms requires sound logistics, not always available.

Even long distances between the field and the coast aggravates the situation. The price of underwater pipes is a function of the distance. This is why the oil companies involved in offshore exploration must take into consideration all the new suggestions or methods, offering technical and financial suitable solutions on the aspects of

— support or production facilities
— flow-lines
— storage
— transport

The ELF Group in this respect has been working on two main projects:

1 — Articulated Platforms
2 — Underwater Storage Tanks

Articulated or oscillating platforms

From bottom to top, the oscillating platforms are made up of:

1) a base lying on the sea floor and representing the fixed point.
2) a universal joint connecting the base to the foot of the cylinder.
3) an emerging cylinder (cylindrical or tubular, following the expected uses).
4) floating tanks under the sea level either linked to the platform or incorporated into it, which provide for the stability of the cylinder. The upward force resulting from these tanks is compensated by ballasting the bottom of the cylinder.
5) a top covering the whole structure and providing for the required functions, drilling, exploitation, separation, living accommodation, and loading.

When the sea is calm, the platform does not move and no force is exerted on the rotating joint. When the sea is rough the platform oscillates in motion with the waves and so bears a much lesser resistance to wave forces than an equivalent fixed platform would.

The maximum inclination angle is limited by the size of the floating tanks.

ELF and Aquitaine with French Companies, have built a prototype named "ELFOCEAN" which has been set up in the Bay of Biscay (Diagram on page 18).

Meteorological conditions

Maximum waves — 65 ft — period 16 sec.
Current — 2 knots
Wind — 135 miles/hour
— Total height of the column — 408 feet
— Base 69 x 79 x 13.9 ft.
— Universal Joint (12,000#)
— Cylindrical tank —— height: 355 feet diameter: 23 feet
— Top — cylinder — diameter: 34.4 feet height: 24.6 feet

Lateral tanks —
Number: 6
Height: 56.7
: 14.7

This platform was set up in 10 days in August 1968. Up to now we have no particular problems whatsoever.

Maximum waves encountered: 40 foot
Wind: 80 mile/hour

The platform is motionless about 90% of the time.

Costs

The price of the prototype averaged 50¢/lb. Right now we pay 55 ¢/lb. for platforms in 160 feet of water.

With French construction costs we anticipate that for higher tonnage the price will drop to around 45 ¢/lb.

Future prospects

The French Company in charge of this project has just studied such an oscillating platform for 1200 feet of water. The drilling rigs would be installed on the platform, 60 directional wells could be drilled.

These wells would be completed with underwater well-heads. The cost figures seem attractive.

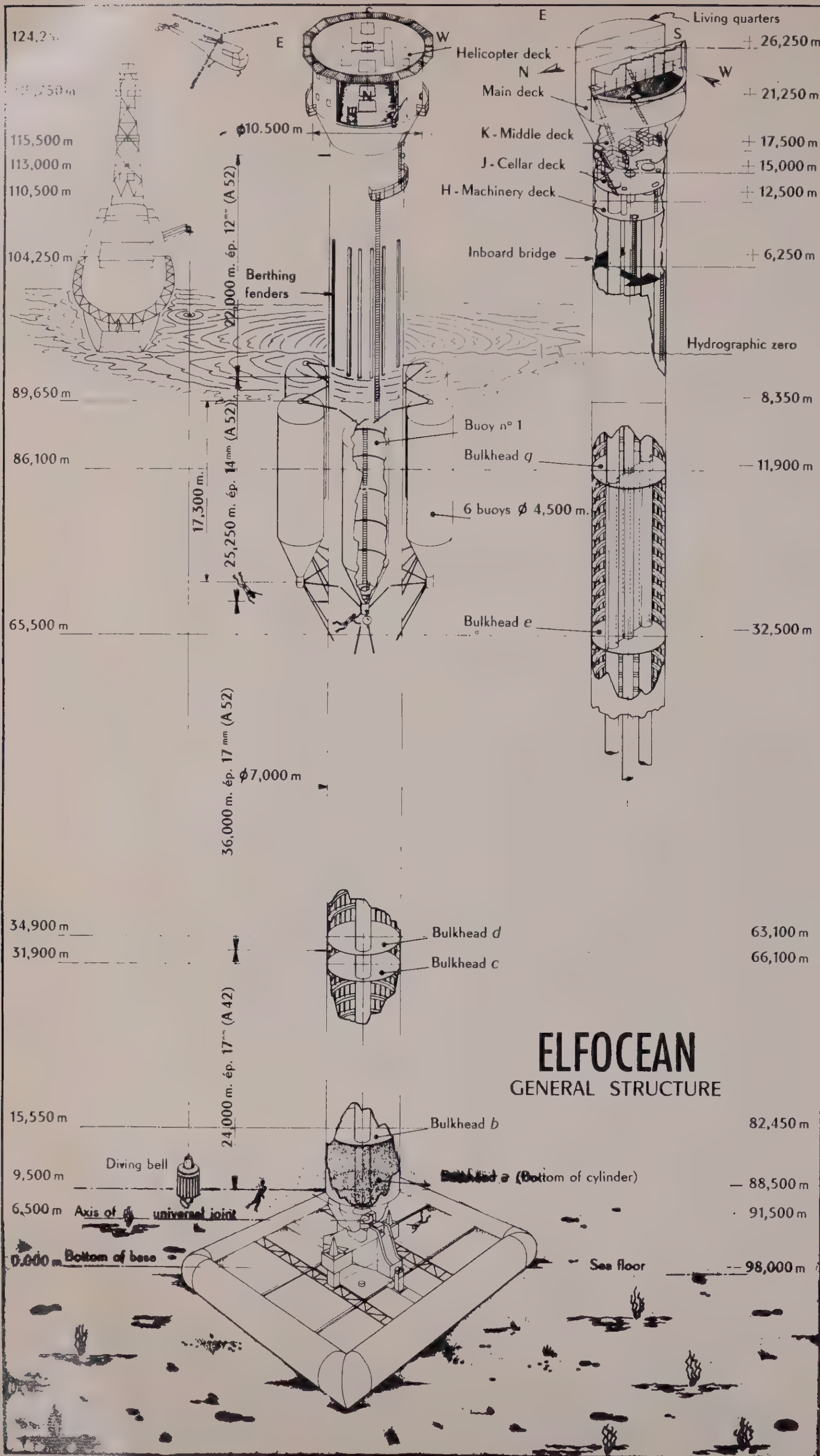
Conclusions:

This oscillating platform is a big step forward for the exploration and production of deep water offshore wells.

2. Underwater storage tanks

Just a few words on the project. ELF Group has been studying 2 different types:

1. Steel underwater storage tank



2. Pre-stressed concrete tank.

We are planning to set up a prototype in the Bay of Biscay although no decision has been taken yet.

STEEL — TANK

Gross Capacity — 660,000 bbl
Gross net capacity — 600,000
It has a dodecagonal shape —
Widest horizontal measurement — 332′
Total height — 76′

PRE-STRESSED CONCRETE TANK

Gross capacity — 440,000 bbl
Net capacity — 400,000 bbl
It has a cylindrical shape. Outside diameter, 243′; Total height, 66′.

The combination of underwater storage tanks and oscillating platforms permits the production of any large fields from the coast.

(3) SURVEYS, DEVELOPMENT & MANAGEMENT OF RENEWABLE RESOURCES:

In this session, three problems of general and critical concern to man were discussed with specific reference to cold waters. Dr. C. J. Kerswill, in dealing with the natural renewable resources of the Canadian Arctic, pointed out that while our northern waters are not highly productive, they are capable of further exploitation and are important in maintaining the economic viability of present northern settlements. Mr. R. H. Millest's paper followed naturally since he was concerned with possible man-made changes in the aquatic environment which would lessen its resource value. As he indicated, pollution in cold waters presents several special challenges to scientists and engineers. Finally, Mr. G. Burt dealt with the field of recreation . . . an area which is assuming ever-increasing sociological importance. Evidently the growing numbers of sports scuba divers are faced with several problems, some economic, some relating to inadequacies of equipment in cold water, others associated with pollution.

J. M. Anderson

FISHERIES AND SEALING

by Dr. C. J. Kerswill*

Surveys by the Fisheries Research Board of Canada and McGill University over the past 20 years reveal that there are at least 200 species of marine fishes and at least 35 species of freshwater and anadromous fish in the Arctic. Most species are of interest only to fish taxonomists. The fishes with greatest economic potential are arctic char, lake trout, whitefish, cod, capelin and sea herring, all characterized by slow growth rate and/or small size. The two most valuable species are probably the whitefish, used extensively as food by the natives, and arctic char, which is highly prized as a sport fish.

The work of the FRB's Arctic Biological Station includes biological oceanography . . . a study of the aquatic environment occupied by both fish and mammals, including studies of the trophic relationships from primary plant producers through zooplankton and zoobenthos (bottom fauna) to usable fishery resources. Until recently most of this work was done during the relatively short summer season of open water; but in 1967 year-round operations were started on hydrographic and biological sampling just off the town of Frobisher Bay in arctic marine water. The 48-ft MV Calanus is used as the summer platform, and sampling is carried on through the ice in winter.

Several species of marine mammals have been investigated in the arctic by FRB scientists and others. Of the truly arctic species, probably the most valuable economically is the ringed seal which occurs across all of northern Canada. It is used extensively by the natives, who shoot the seals, dry the skins and commonly sell them to Hudson Bay Company stores. Prices vary from year to year but have been as high as $25 to $30 recently. Most of the scientific studies of ringed seal have been in the eastern arctic, but investigations of population dynamics have now been extended westward. The walrus provides some food for the natives and the tusks are worth about $50 each for the ivory. The narwhal is used mainly for food, but its single tusk is worth about $50 as a curio. The white whale, or beluga, occurs in Hudson Bay and northward around Baffin Island, and has been fished commercially to some extent for its oil and skin (the latter has been used for dress belts). Present plans call for the improvement of population estimates by aerial photography to supplement tagging, which has been in progress for several years. Harp seals are hunted to some extent by natives in the north, but the main fishery is off the Atlantic Provinces in spring, for whitecoat pups.

There is a population of arctic cod (*Gadus ogac*) at Cambridge Bay which compares favourably in quality with the Atlantic cod (*Gadus morhua*), but exploitation is not economically feasible at present. Greenland halibut has potential off eastern Baffin Island, and exploration of its distribution and availability is needed. Groundfish, including Atlantic cod, have been fished to some extent by natives in Ungava Bay area recently, and systematic surveys are now at the planning stage. Rumours many years ago of vast untapped fish resources in Hudson and James Bays have proved to be generally groundless, but there are some prospects for development of a shrimp fishery. Hopes for long-continuing commercial fisheries of marine species in the arctic are poor because of the slow growth rate of all species, and the high cost of transportation. But some of the stocks, like that of arctic cod, might become valuable commodities for local use in settlements that may occur around mining and other industrial developments.

The anadromous form of the arctic char is now providing a valuable fishery at several points in the arctic. For example, the Department of Indian Affairs and Northern Development has recently sponsored a plant at Wellington Bay, Victoria Island, where about 100 thousand pounds of excellent char are frozen and exported to southern points annually. At Frobisher Bay there is a 5,000-pound annual quota for char caught locally by natives. In 1966 this quota permitted the take of 1,700 fish, averaging 6 pounds in weight.

In a recent study of landlocked arctic char in 125-acre Keyhole Lake on Victoria Island, NWT, it was found that the maximum annual yield is about 6 kg. (5.5 lb.) per acre, leaving sufficient stock for adequate egg deposition. This is considerably higher than expected, and is attributed to the low trophic level of feeding by these fish — zooplankton and insects — rather than fish and larger invertebrates, the usual diet of trout and char.

Lake trout have widespread distribution in large lakes like Great Slave and Great Bear, and hundreds of smaller lakes. Often they are fished commercially, sometimes in association with whitefish and ciscoes. Usually the fisheries are under a systematic management scheme, involving rotational fishing from year to year, and are quite valuable.

Population estimates and approximate present annual catches of four species of marine mammals are as follows:

	Estimated Population	Approximate Annual Catch
Narwhal	10,000	100
Walrus	25,000	200
White whale	40,000	200
Ringed seal	2,000,000	70,000

Natives in the Northwest Territories number about 20,000 (Eskimos, 13,000; Indians, 7,000). Dogs average about one per Eskimo.

The potential annual commercial fish production in the Northwest Territories is estimated to be about 5 million pounds of marine species, and 18 million pounds of freshwater and anadromous species. There is practically no utilization of marine species at present, while about 6 million pounds of freshwater and anadromous species are fished commercially per year. Besides these commercial fisheries, the sled dogs of the Eskimos consume about 5 pounds of fish per animal per day, totalling about 20 million pounds.

The relative importance of the above potential fish production from Northwest Territories waters is indicated by comparing the 5 million pounds of marine fishes with the present 2,200 million pounds annually for all of Canada (2%), and the 18 million pounds of freshwater and anadromous with present Canadian annual total of 138 million pounds (13%)

Although Canada's cold northern seas, lakes and rivers may appear to have modest fisheries potential in comparison with more temperate waters, it must be emphasized that the arctic fish and sea mammals have inestimable value to the natives, who still depend extensively on them for food, clothing and general well-being.

*Director, Fisheries Research Board Arctic Biological Station, Ste. Anne de Bellevue, P.Q.

Pollution control and pollution engineering

by R. H. Millest*

The development of industry in Canada's far north, and with it the likely growth of communities into cities of substantial size, presents the sanitary engineer, and others concerned with pollution control, a challenge the like of which he has probably never seen before.

To appreciate some of the problems which are to be faced, let us look at the tools with which we now have to work — the state of the art, as it were, and consider for a moment how these can be applied in the extreme conditions of the Arctic.

Municipal waste treatment, as presently practised, is based on fairly well established physical and biological processes which were developed, for the most part, to effect, in a controlled environment, what took place naturally in the water environment. Settleable solids, that is those solids which can be removed from suspension by, say, 30 minutes of quiescent standing, are removed as a sludge, are then usually digested anaerobically to reduce their volume by reducing them to a humus-like material, and then disposed of on the land, or, in some cases, by incineration. The remaining organic waste components, both in solution and in fine suspension, are stabilized by biological oxidation, some then being removed in a secondary settling stage as part of the biological sludge and the remainder being discharged to the receiving waters. Until recently, waste treatment has been considered to be adequate when the effluent is clear and the residual organic components are oxidized to the point where there is no appreciable depletion of dissolved oxygen in the receiving waters. Disinfection of the final effluent by chlorination or other means is frequently practised where downstream water supplies or recreational areas are to be considered.

But as the quantities of sewage and wastes have increased, it has been found that even the relatively stable residual of well treated wastes have an adverse effect on the receiving waters. I refer, of course, to the rapidly accelerating eutrophication of many of our lakes. It is apparent now that more complete treatment is required if pollution is to be really effective.

Assuming, however, that we succeed, as we must, to up-grade sewage and industrial waste treatment to eliminate the adverse effects on surface waters, what will be the effectiveness of treatment in cold climates when we use the technology that has been developed for the temperate climate? Can we make the conventional systems work when we are faced with permafrost and prolonged sub-zero weather conditions? Let me touch on some of the questions which will have to be answered in the field of water supply as well as waste treatment.

Present research in the far north indicates that community water supplies will have to be heated or suitably insulated to prevent freezing when the distribution system extends for more than a few city blocks. Communities will have to be far more compact than those in the south to make any large-scale distribution of water feasible, suggesting that town planning will have to take this into account as a major concern. Since domestic water consumption is very low during the night, dead-end water lines would quickly freeze without continuous flow, suggesting that all lines would have to be looped back to a pumping station to permit continuous circulation and heat in-put.

The problems of sewage collection, treatment, and disposal are even more imposing. We can assume that it might be necessary to ensure that sewage is heated in one way or another, to prevent freezing of the sewers. But then what of the treatment methods? If temperature of sewage fell off rapidly it is likely that conventional clarifiers would freeze, at least to the extent that sludge scraper mechanisms would fail to operate. The efficiency of biological treatment processes falls off very rapidly below 45°F with the result that very large treatment plants would have to be provided to produce the same degree of treatment as effected in temperate climates. Otherwise, rather ineffective treatment would be given for much of the year in Arctic and even sub-Arctic climates.

Sewage lagoons, i.e. simple oxidation basins, would perhaps have some application for small communities but these would have to be relatively large to permit long-term retention, with effective operation limited to the summer season. Lagoons would have to be located as close as possible to the community to avoid long delivery sewers (which would freeze in winter) and it is obvious that this could present a problem in the summer months.

The greatest challenge in pollution control will most certainly lie in the field of industrial wastes. With the potential for petroleum developments in the far north, waste treatment that is not completely satisfactory, even in the south, will have to be up-graded or new methods devised, if pollution is to be avoided. Existing treatment methods rely, to some extent, on the natural purification processes in the receiving water, to eliminate residuals of waste components remaining in wastewaters. Phenols, for example, are broken down as they enter into the natural biological system, in natural waters, but what will be their fate in cold northern waters? We know that they are exceedingly persistent in warm water — will they persist still longer in the north? The knowledge which we now have on the rates of recovery of rivers that are subjected to pollution, in which the zone of recovery is much longer in winter than in summer, suggests that many waste components will indeed persist for long distances in the far north. The possible adverse effects on water supplies and fisheries will then be more significant than in warm water, and, in the case of tidal estuaries or inlets, may lead to a continuing build-up of pollutants that would render the waters completely unusable.

There are many facets of water supply and waste treatment to be examined. The question will be how to direct attention to the special nature of northern pollution problems when we can barely cope with those we now have in the south where the pressures of population are greatest. We must apply the resources we have, however, and develop a technology for these and other environmental problems if we are to realize the potential which lies in the north.

*Chief, Water Quality Division,
Department of Energy, Mines and Resources,
Ottawa

RECREATION

by G. A. Burt*

Few recreational sports in Canada have experienced such rapid growth as diving, starting in the mid fifties and having its greatest expansion in the early sixties. Several American companies established assembly, distribution and sales offices in order to capitalize on the market. It was only a short time later that our Government set up protection for Canadian owned and operated enterprises, forcing the American companies to withdraw from the market. Prices increased imme-

* [illegible], Association of Canadian
Underwater Councils, Mississauga, Ontario

diately and today the Canadian diver and industry pays between a 45% to 55% premium. Due to this incremental increase many of the would-be participants found that costs prohibited them from this recreational pastime.

We currently pay, therefore, a great deal more than our neighbors to the south, all because our Government has imposed tariffs for the protection of non-existant Canadian manufacturers of similar equipment.

Some D.B.S. figures which may be of interest to you indicate that in 1968, 6.87 million dollars worth of recreational equipment was imported and that an estimated 3% of this represented diving and water sports equipment, or $206,000. This of course is a landed cost and would represent 1 to 3 ratio by the time the product reaches the consumer. Our Government is taking the shark's share of the profits, taking more in percentage than either the importer, distributor or the dealer.

One of two things has to happen: either the Government must lift these totally unfair discriminatory tariffs, or our protected Canadian manufacturers are going to get up off their protected butts and produce. We say this has to happen, because if it does not we are not going to realize the expansion which is becoming increasingly necessary in this field. Hopefully some of the sophisticated commercial Canadian diving equipment companies could receive assistance in the quality production of the type of equipment required by underwater enthusiasts. Also necessary is the production of equipment for the Canadian cold water diver, since for the most part the equipment now available has been designed for tropical waters. An example of this is plastic straps which become rigid, regulators which freeze up, and inadequate cold water exposure suits.

Production of this type of equipment could also satisfy the needs of other nations with similar requirements, and could provide substantial export opportunities.

Growth and development

The Canadian sports diver is truly a Man in Cold Water. Even during the warmest months of the year, his activities take place in what you would have to term cold water conditions. To a limited degree he swims under ice covered waters, but with the present exposure protection this is naturally limited. In spite of the limitations, the organization continues to grow. The Ontario Underwater Council has a membership of over 1800, exceeding all the other councils who are in the prime diving areas such as California or Florida. The Underwater Club of Canada has a membership of over 300 and operates three Diver Training Locations. We are well organized and our members are keen and share a wide and varied interest in almost all aspects of underwater activities. However, this is still not sufficient. If we are to command a position in this field we must expand in numbers far exceeding the present. Without a significant increase no manufacturer will find it economically possible to profit from production of equipment and there will not be enough desire for education in this field and our teaching institution will lack the enrolment to make a program of value available.

Water pollution

Water pollution of course concerns us all. We are affected in the sport since we are required to travel long distances away from populated areas in order to find water conditions which are conducive to enjoyable exploration and healthy part tion. The only benefactors to this l travel situation are the petroleum, aut and tourist industries. Pollution not only reduces underwater visibility, it also reduces the plant and animal life available for interest and study. Once well-populated areas have now become barren underwater waste lands due to abuse. Unless this trend is reversed we will have to travel even further distances.

At this time this may not represent much concern, but with the increased amount of leisure time, emphasis on fitness, and more disposable incomes the effect is bound to be felt. Certainly we should look on the improvement of our present conditions as an investment in our renewable resources.

Awareness and development

A concerted effort must be made to make all Canadians aware of our aquatic environment. No other nation in the world has so much to lose if we do not move to understand, protect and develop our underwater resources.

In my opinion the time is right. By 1970 over 50% of this country's citizens will be under the age of twenty five. We must encourage our young people to enter these aquatic fields. We are convinced that a large number of those who become interested in the recreational aspect will find employment in the scientific and technological fields.

We are fortunate to live in a young democratic country. We have a unique opportunity. We have missed out in such areas as space, rapid transit and other important fields. We have the enthusiasm, the environment and the experience. We also have the talent. We in the Sport are prepared to take up this challenge.

(4) UNDERWATER ASPECTS OF TRANSPORTATION IN ICE-COVERED WATERS:

HARBOURS IN COLD WATER

by David H. Sharp*

1. Looking into the Far North in search of safe harbours there is a natural tendency to project previous experience into the new environment, and to use if possible the tried and true methods of the past. This paper takes a look at these methods of approach and at some modifications and variations which may be tried.

2. Some of the Northern conditions which are of interest are as follows:

.1 *Precipitation* 9 to 10″ per year, in the High North. This may be in the form of rain but mostly it is in the form of snow. Snow drifts would blow about five feet high.

.2 *Moistures in Ores.* Copper Mine Ore 6 to 8%. Mary River Iron Ore, almost no moisture.

.3 *Rafted Ice.* 20 to 30 feet thick on the Alaska Shore.

.4 *Undisturbed Homogeneous Ice.* 80″ maximum thickness on the Alaska Shore, and 48 to 60″ maximum thickness in the Canadian Arctic.

.5 *Perma Frost* melts for about 18″ depth in the Canadian Arctic.

3. *CONVENTIONAL METHODS OF HARBOUR CONSTRUCTION* include:

.1 The use of steel sheet piling, timber or concrete cribs, and piling of one kind or another. The objection to all of these is the amount of site work which must be done and their vulnerability during construction; also the chance of their destruction by ice pressure if they are not completed in a season free of ice. A type of construction which would minimize site work and underwater work would be preferred.

.2 *Jack Up Type Dock.* This has much to recommend it, in that it is to a great extent factory made, and does not require preparation of the bottom. Its location must naturally be chosen to keep the length of legs to a minimum and their support to a maximum. Even so they may need horizontal support

*Vice-president and Director, Howe International Limited

such as at Thule where earth is piled behind the dock and the front legs are longer than the back legs.

.- The use of floating type docks would seem to be a slim possibility because of the requirement of their protection from ice. There is the possibility that such a dock could be sunk for the off season and raised the next season.

4. *SOME CONSIDERATIONS, WHEN THINKING OF BUILDING MARINE TERMINALS IN THE NORTH*

.1 Structures should be on rock if possible.
.2 They should be located to miss Perma Frost if possible, i.e. use underwater foundations.
.3 Use prefabricated and preferably factory made products if possible.
.4 Avoid cross bracing on docks. It can be self-destructing.
.5 Avoid having to go through ice, rather go over it.
.6 Get a location where shore fast ice does not pile up, i.e. a place where there is no ice pressure on the shore.
.7 Avoid areas where deformation of ice is likely to occur.
.8 Avoid multiple handling of the product.
.9 Prevent heat transmission to the ground.

5. I conclude from experience that:

.1 Installations should be as rugged and as simple as possible. The extent to which this principle is followed depends to a great extent on the isolation of the location.
.2 Transhipment should be cut to a minimum.
.3 Loading and off loading of ships should be expeditious.
.4 Ships must be able to locate themselves accurately in all weathers.
.5 Weather information must be readily available.
.6 Ice information must also be readily available.
.7 All information must be reliable.

6. One of the main bulk shipments from the North will be oil, another will be ore and ore concentrates. Regarding *Bulk Ore Shipments* it would be safe to assume that the economics of such shipments must be studied at each site. Some factors for consideration are:

.1 Tonnage, specific gravity, size and value of ore per ton.
.2 Moisture content.
.3 Length of the season, taking into account all possible modes of transportation.
.4 Distance ore must be transported land from mine to shipping point.
.5 Length of sea journey.
.6 The possibility of running a continuous operation, both at the mine and as far as transportation to market is concerned.
.7 Ice conditions at the site and along the sea route.
.8 Weather conditions throughout the year, both at the site and along the sea routes.
.9 General site transportation.
.10 Housing.
.11 Communications.
.12 Ship loading and off loading.

7. The following are some thoughts which follow from a consideration of the above headings. They are offered for discussion and further investigation.

.1 What about the mooring of ships to buoys which may be submerged after use if necessary? The sea, cold as it is, is still above freezing and has its uses. The accomplishment of this could conceivably be by having the ship stop and anchor at a specific location, identified positively from shore. An internal hatch would be opened allowing the pick up of an underwater air line through the bottom of the ship, *where there is no ice*. From a compressor on board air would be blown into say 4 buoys, of sufficient size to break through any ice cover expected. Afterwards the air is allowed to exhaust and the buoys then sink again.
.2 It seems reasonable to assume that pipe for loading oil could be handled in the same way.
.3 If it is not possible at the chosen site to berth the ship as close to shore as desired, it may be worth looking into the use of a dock which may be raised or sunk as previously mentioned.
.4 It may not be possible to put the dock near enough to shore to be able to bridge the gap. In this case an intermediate small dock or platform could be used and raised in the same way.
.5 It may be said that it is rather impractical to plan on the above type of operation. I am suggesting that it is worth looking into, and that whoever does that should be someone who has imagination and is not afraid to consider the unusual.
.6 The ice may be thick but let us remember that a submarine can break through 8′ of ice.
.7 *Barges.* Let us assume that direct shipping ore is to be loaded and shipped out if possible. I ask you to consider the use of dumb barges of 50,000 d.w.t. to 100,000 d.w.t. capacity, about 40′ draft. The routine might be as follows:

.1 Load ore direct into the barges. This would save stockpiling and reclaiming equipment, its support on Perma Frost, probably, its maintenance and the shops and men required for that.
.2 The barges would be fitted with Alexbow or M.I.T. icebreaking bows.
.3 A shuttle service might be organized from a site in the Canadian Arctic to the Western shore of Greenland, which is ice free the year around up to about the 65th Parallel. The second leg of the journey would commence there.
.4 Different sizes of tugs used as pushers would be used. Whereas a 15,000 shaft H.P. tug might be required for a 50,000 d.w.t. barge for the first leg, something in the neighbourhood of a 5,000 shaft H.P. tug, used as a pusher, would probably do for the second leg.
.5 The length of the season is very important. As an example Milne Inlet could probably be used for six to nine months per year. The Churchill season is only three months but could probably be greatly increased.
.6 Allowing say two barges always at the site, it is thought that a circuit using a reasonable number of barges may be worked out. The mining programme can be tailored to suit the seasons somewhat.
.7 As the tug arrives with an empty barge he has broken a channel through the ice. He leaves immediately with a full one through the same passage. There may be a barge or two a day.
.8 If ore can be loaded as mined into barges, it will not be necessary to provide very fast loading equipment in order to be able to turn the ship around quickly.
.9 Tugs for 25,000 d.w.t. barges would be 10,000 - 12,000 shp. in the Canadian Arctic and as before about 5,000 shp. for the second leg. Travel would be say 9 knots. 10 days to Philadelphia.

.8 Another consideration is that of building docks of a saw tooth variety so that ice pressure on the shore will tend to break up the ice. For instance, in plan, a dock may consist of three large teeth. Those at each end for fendering and the center one for some kind of ship loader. As an alternative the ship may be held off the dock face by mooring buoys and only the center tooth provided. The teeth should face in the right direction. These teeth would terminate in points of about 10′ rad.
.9 Containers could be a great help because they are quickly unloaded and provide their own warehousing and are loaded as usual at the same time as the empties are off loaded.
.10 The ores may as stated be quite dry. However there is the possibility that during the sea voyage the ores will consolidate into a solid mass and be hard to unload especially if shipped in bulk. Again we must remember that the sea is above freezing and there is lots of it. It can be used in great quantity to thaw out the cargo.

8. In closing, I would stress the necessity of having available pertinent information on this vast area, and I am glad to learn that the collection and correlation of it is now in the hands of one of our most well known authorities on the North.

9. Many countries are interested. Many minds are at work. All will base conclusions and action on such information. Therefore it must be reliable, for not only work but life can depend on it.

UNDER ICE HABITATION

by Lieut. Cmdr. B. F. Ackerman, R.C.N. (Rtd.)*

There have been about 20 saturation diving experiments since 1962. Many of these have been located geographically where conditions were favourable and convenient.

If the success of saturation diving is to be exploited in the environment typical of Canada, a new approach to the support system will be required. The problems of ice, cold and remoteness must be solved.

This concept, we have chosen to call the "Sir John Franklin", is for a towed barge-type of surface support diving vessel, to be positioned during the ice-free season and then frozen in for the winter. Once fast in the ice it will function as a home and laboratory for up to 12 men, provisioned for 10 months, and a base for an underwater pressure proof type vehicle. The base will be pressurized to a sea water equivalent of 20 feet to keep the water interface well below the ice line. Since the diver occupants will become saturated at 20 feet their no decompression depth limits will be extended.

Figure I (p. 24) illustrates the general arrangement. Power for heat, light, cooking, recharging submersible's batteries etc.; comes from a separatable module containing the diesel-electric plant. In this way noise, vibration, fumes and fire hazard are removed from the inhabited portion. This arrangement makes it possible to operate the vessel completely submerged as a bottom residence.

It is supplied with a closed environment making it independent of surface air supply. When used as a surface habitat this will reduce the heating cost and eliminate the low humidity problem common to surface buildings using heated outside air during the Arctic winter. When used as a sea floor residence the atmosphere will be tailored for the depth.

Before advancing to an "under-ice-sea-floor residence-diving" stage the system will be thoroughly tested on the surface. Once proven an identical vessel will be attached to a weighted stand and positioned beneath its "sister ship" support base. In this mode the deck house will be removed to permit a submersible decompression chamber to lock on to the vessels recompression chamber access trunk.

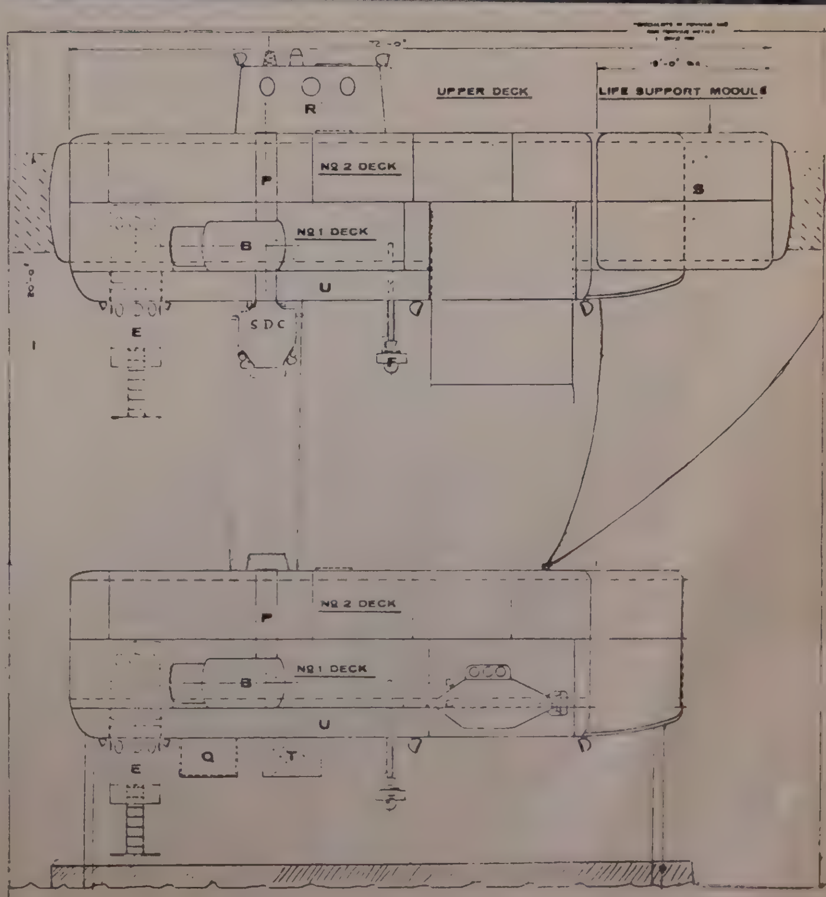


Figure 2 →

Safety arrangements

A recompression chamber (B) provides therapeutic and prophylactic decompression for divers. When there is no diving in progress the RCC can serve as a laboratory facility permitting the use of toxic chemicals. When so used the RCC will be kept at slight negative pressure with respect to habitats atmosphere so there is no danger of fumes contaminating the closed atmosphere. Fumes will be vented

*Diving Consultant, Northern Associates Reg'd

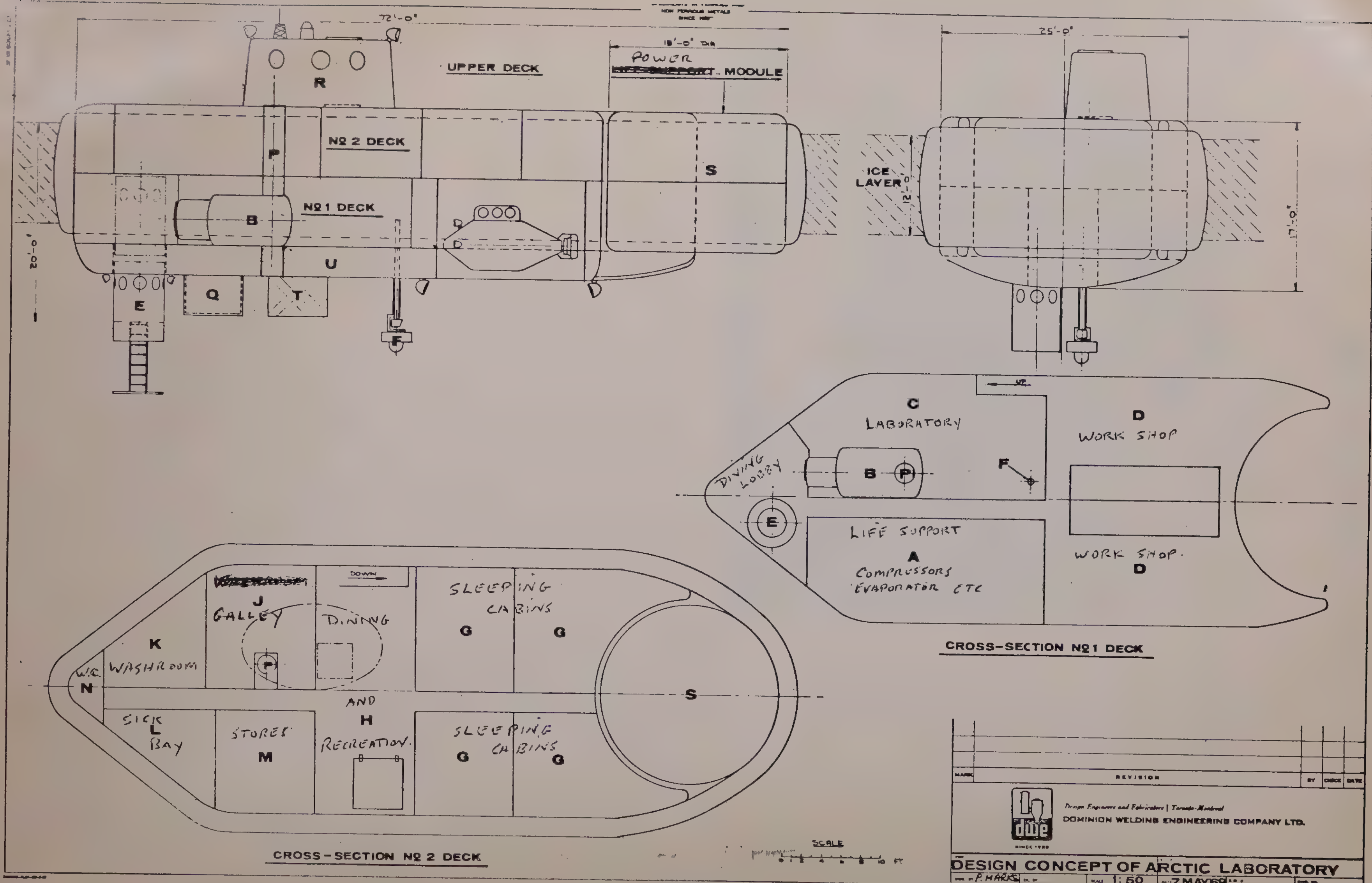

72'-0"
UPPER DECK
18'-0" DIA
POWER ~~LIFE SUPPORT~~ MODULE
R
P
Nº 2 DECK
Nº 1 DECK
B
U
S
E
Q
T
F
20'-0"
25'-0"
ICE LAYER
12'-0"
17'-0"
C
LABORATORY
D
WORK SHOP
DIVING LOBBY
B
P
F
E
LIFE SUPPORT
A
COMPRESSORS
EVAPORATOR ETC
WORK SHOP
D
UP
CROSS-SECTION Nº1 DECK
J
GALLEY
DINING
DOWN
SLEEPING CABINS
G
G
K
WASHROOM
W.C.
N
P
S
AND
H
RECREATION
SICK
L
BAY
STORES
M
SLEEPING CABINS
G
G
CROSS-SECTION Nº 2 DECK
SCALE
10 FT
REVISION
MARK
BY
CHECK
DATE
DOMINION WELDING ENGINEERING COMPANY LTD.
DESIGN CONCEPT OF ARCTIC LABORATORY
P. MARKS
1:50
7 MAY 69
AL.3.

Figure 1

to outside atmosphere. The RCC also serves as a man lock to the outside or an SDC.

When used on the surface a deck house is provided over the RCC access trunk to house surface survival equipment i.e. tents, sleeping bags, radio equipment etc.;

A submersible decompression chamber Fig. 2 will be carried in the submersible bay when the vessel is going to be used as a surface support base. This will then be installed on a lower access trunk to the vessel's RCC, from where it can be lowered to marry up with an adopter on sea-floor unit. Thus personnel can undergo the long decompression when returning to the surface from their saturated state in the two RCCs.

SUBMERSIBLE VEHICLE

Is of an existing proven design having the following characteristics:

Weight:	4,500 lbs.
Length overall	12 ft.
Height overall	6 ft.
Width	42 in.
Speed	2 kts.
Battery endurance	8 hrs.
Life support endurance	24 hrs.
Depth maximum	1,000 ft.
Crew max.	3
Crew normal	2

Navigation is normally from a plot generated by a sonar scan. The mersible is given vectoring information i underwater sound voice link. Visual data are recorded on tape.

A new system is planned for under ice navigation as a back up. This will be developed from proven components and techniques.

Work to date using this vessel includes:

Offshore petroleum exploration. Mapping of rock outcrops, structural attitudes, key bed and fault tracing, measuring and sampling of stratigraphic sections.

Total environment studies of geology, physics, chemistry and biology to a depth of 1000 ft.

The status of the submersible as a useful tool for offshore res ource recovery

by Thomas F. Horton*

Mr. Horton's article was copyrighted by the Offshore Technology Conference, May 1969, Houston, Texas; sponsored by the Marine Technology Society.

Five years ago on the first of March 1964, the Shell Oil Co. leased the services of the Cousteau Diving Saucer for a one day operation to evaluate the submersible in terms of its usefulness as an observation inspection tool for a subsea production well-head. This operation was conducted off of Gaviota in the Santa Barbara Channel. To my knowledge this was one of the first uses of a manned submersible as a useful tool for offshore resource recovery.

The offshore resources industry has changed and progressed dramatically in the past five years. This is particularly true of the offshore petroleum industry. In this five year period, thousands of acres of underseas leases have been taken and at greater and greater depths. New technology in both exploration drilling and production have been developed. Millions of dollars have been invested in new equipment and tools for offshore resource production.

If we consider the 1960's as the beginning decade for submersibles then the first five years, 1960 to 1965, will have to be considered as the planning and design phase of the first generation boats.

During this period the design and fabrication of a variety of submersibles was accomplished. This would include, the Perry Family of Submarines starting with the Cubmarine. In all, the Perry submarine builders have manufactured five submersibles.

General Mills/Litton designed the Alvin, which has been effectively operated by Woodshole up to late 1968 when a Handling System failed, dropping Alvin into approximately 4,300 ft. where she now lies, but fortunately without injury or loss of life.

General Dynamics electric boat division have produced more large submersibles, at this time, than any other company. This would include the three Star Boats, Aluminaut, and two Alvin type submersibles for the Navy.

Westinghouse have now completed well over 500 dives with the Deepstar 4000 submersible. Deepstar is an excellent example of the first generation submersible and the problems of adapting what was basically an observation chamber into a work boat. Deepstar is equipped with a

"Pisces II", first of four 3,500 and 6,500 ft. submersibles being built and operated by International Hydrodynamics Company Limited.

*President, International Hydrodynamics Company Limited, Vancouver, B.C.

very frail manipulator and a three segmented claw which will lift 25 to 40 lbs. Since the first contact for the submersible was in the area of Scientific Data [illegible]king, a technique for carrying instruments weighing more than the submersible's payload, had to be found. The instrument packages also had to be mounted in such a way as to allow visual observation by the observer and pilot. The weight and placement of the instruments was also considered so as not to affect trim. Engineers from the U.S. Naval Undersea Warfare Center in San Diego solved the problem by designing an attachment rack for the instruments, which mounted on the front of the Deepstar in view of the occupants, buoyancy was accomplished by adding special syntactic foam which offset the instruments' weight.

International Hydrodynamics have completed two manned submersibles . . . the PISCES I for 2000 ft. depths and the PISCES II a 3500 ft. depth submersible. PISCES III a second 3500 ft. boat is about 60% completed. In addition, two Hy 100 steel hulls are being machined by Vickers, in England, for International Hydrodynamics, for their two 6,500 ft. depth boats PISCES IV and V.

In Santa Barbara General Motors AC Electronics Division have built and are operating the DOWB, deep ocean work boat. This 6,500 ft. depth submersible is used primarily for operation in the A.C. Electronics and Acoustic range but is also available for lease operations.

Two other submersibles should also be noted and considered for offshore resource applications, these are the Reynolds International Aluminaut and the Lockheed Deepquest. Both of these boats are capable of at least 8,200 ft. depths or greater, long dive duration, high payload capability and like many other smaller boats remote arms or manipulators are included.

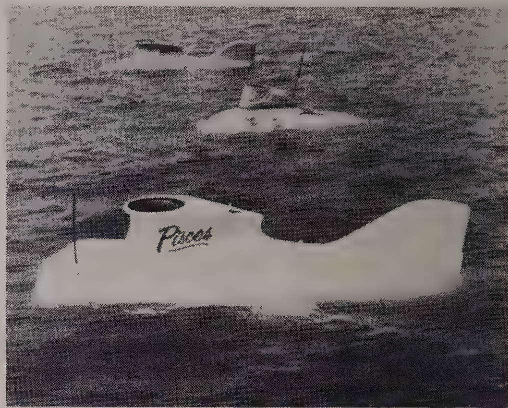
In the past three years only two significant second generation submersibles have been completed.

North American Rockwell designed and completed the Beaver Mark IV "Roughneck." This 2000 ft. depth boat is equipped with two manipulators and a fairly extensive tool set and rack. In addition, diver lock-out can be accomplished as well as the ability of the submersible to mate to a habitat and effect a dry personnel transfer. Diver lock-out or habitat mating have not been actually accomplished as of the writing of this paper, but should be effected before Summer 1969.

Diver lock-out to approximately 700 feet has been carried out on a number of occasions utilizing the Perry Deep Diver and the Perry Shelf Diver. Perry have also successfully mated the Shelf Diver, an 800 ft. depth submersible with a diver lock-out capability to 50 feet, to an ambient pressure habitat, Hydrolab, and made a dry personnel transfer.

These then are the manned capsules that are presently available for work tasks in the sea. What then are some of the tasks which have been accomplished? First, we must consider the kind of [illegible] required in the offshore resources [illegible]. Although the tasks requested vary between the petroleum, mineral, fishing, construction and salvage industries, the submersible has been used to solve a great variety of tasks.

Although many techniques have been used for site surveys, visual inspection and search, the submersible is the only free swimming and mobile, one atmosphere, personnel carry-all, that provides the viewer an actual "eye ball" inspection of the environment. For quick inspections, it is reasoned that the submersible is a very expensive and difficult to support technique. Unfortunately this is true. Mobilization, crew requirements, transport to site and logistic support represent a fairly high per dive cost to the user as compared with divers or underwater television. However, beyond the 600 ft. depths, submersibles can be used competitively with other inspection techniques. As an example, Perry, Electric Boat or International Hydrodynamics can provide repetitive dives, on a quick reaction basis, for less than $2,000.00 per day. This is actually less than the cost of a mixed gas decompression dive by a diver and provides the non-diving engineer with direct observation rather than having to rely on a diver description or review of a T.V. tape. These submersibles are capable of repetitive dives, whereas this cannot be done by divers except in a saturation condition using a diving chamber or conventionally by a team of divers.



A fleet of "Pisces" riding abeam of one another before being shipped to the United Kingdom.

As an example, several one-ton oceanographic data systems were visually inspected and photographed at about 1000 feet from PISCES I. These systems had been placed on the bottom a year earlier in the Canadian Arctic. PISCES I made 15 dives over a six-week period, operating from the deck of an ice breaker which transited them from Thule Greenland to the McClure Straits about 2500 miles total distance. This dive series will be of special interest to those companies interested in the Arctic since a considerable number of the dives were made under the ice.

Both Star II and PISCES I have been used by oil companies for anchor inspection, pipe line inspection and for the retrieval of dropped objects. As an example, PISCES I was utilized to recover a dropped foundation pile weighing approximately nine tons from the Sedco oil rig under lease to Shell Oil Company in the Queen Charlotte Straits. Travelling to the semi-submersible drilling platform via an ocean going tug, PISCES I was hoisted aboard the Sedco rig. A wire sling was rigged on the submersible's 21-inch torpedo recovery manipulator, the vessel then submerged towing a three-inch polyprophlene line. After attaching the sling around the end of the foundation pile, the submersible pilot notified the surface via underwater telephone to begin the recovery. The submersible backed away from the pile, then came to the surface leaving the sling attached, the crane proceeded to lift the pile back on to the drilling platform.

This use of a submersible's remote manipulator illustrates what can be accomplished on site and on the spot. However, solutions to longer term problems such as subsea production, wire lining, inspection, repair, maintenance and response to quick reaction problems still require that more new devices be developed. Obviously this will require a considerable investment in venture capital.

At least four companies are working on second generation programs which will be of real value to the subsea resources industry. Foremost of these companies is North American Rockwell and their combined efforts with the Mobil Oil Company to develop a subsea production facility and the support equipment required for the ocean bottom mounted facility.

Perry Submarine builders are also completing modifications to the Hydrolab to make it a one atmosphere observation chamber which will also be equipped with a diver lock-out compartment, and one atmosphere mating and submersible transfer capability. These efforts will provide much additional engineering and operational data which will serve to demonstrate some practical solutions for effective work in the sea.

The most effective second generation submersible available today is the Beaver Mark IV Roughneck equipped with the most sophisticated manipulator and accompanying tool suite of any submersible. Roughneck also boasts a diver lock-out capability and dry transfer capability by mating the submersible to the bottom mounted production facility.

The ability of these small submersibles to achieve diver lock-out will provide a highly mobile system for diver transport. However, the diver has a limited capability in the 600 to 800 foot range and cannot be counted on to perform tasks requiring long exposure on site. Diver lock-out for deep operations is really a substitute for the lack of sophisticated manipulators and tool sets. Given the opportunity to design tools for specific tasks and in conjunction with subsea programs, the submersible engineer will provide the next generation submersible with effective

tools to meet the needs of the subsea resources industry.

Considerable effort of course is already being directed to the development of sophisticated tools for submersibles.

In many cases, the tools developed start off as hand-held items such as the Battelle Memorial Institute's Electric Multi-Speed Drill and their Tying Tool.

In most cases, these hand-held tools can be readily adapted to the available submersible manipulators.

Of particular interest to the off-shore mineral industry is the unique achievement of the Woods Hole Oceanographic Institute.

This organization developed a hard rock coring drill that is attached to the manipulator of the submersible Alvin.

The drill is capable of obtaining a ¾-inch diameter core that is three inches long. The core samples are secured in the diamond drill by the application of a steady low pressure suction provided by a water pump.

Although long soft sediment cores have not as yet been taken by submersibles, it is well within the industry's capability to use submersibles to obtain cores three feet in length or even longer.

Considering that most of the existing submersibles and their tooling have been built on speculation it is rather amazing that they have been used for so many applications. Beginning as pure observation platforms the submersibles have been used for almost every application conceivable in the oil industry with the exception of actually duplicating the diver for production tasks.

What then, is the next step required for the submersible? Unfortunately the use of the submersible is not keeping pace with the current state of the art.

The submersible industry is able today to accomplish far more than the offshore resource industry is aware. Historically the industry seems to require "off the shelf" solutions to quick reaction problems. This approach will not be sufficient to encourage the investment necessary to develop the third generation capability which will be required as the industry moves into deeper water.

What has been learned to date and what will be required for tomorrow? First, the submersible industry has developed a variety of techniques and designs to provide a safe-to-operate, small manned submersible and to do so in a reliable manner. Costs to produce and operate the submersibles have been established and a great variety of components have come onto the market. I would estimate that the submersible manufacturers alone have invested about 50 million dollars of development money into these boats and the Navy an additional 10 million dollars. The offshore resources industry, however, has made only a very small investment in the use of these tools with the exception of two oil companies who jointly have about 7 million dollars invested in the development of subsea production facilities but very little invested in the submersible.

The subsea resources industry is going deeper and deeper and at the same time further from shore. Obviously, this will require new support requirements for tomorrows deeper "oil patch." The submersible can be competitive today with remote or diver systems especially in 500 to 600 foot depths or deeper. More sophisticated systems placed at greater depths will require that the resources industry work closely with the submersible designer and manufacturer.

This requires a systems engineering approach where the resources industry and submersible designer and operator plan the joint operation of their facilities to make the submersible compatible for work tasks. In addition the submersible must be of a size and weight to make it easy to handle from existing work boats, reliable and easy to maintain in the field and of a cost to make it competitive to other systems.

The submersible industry possesses the knowledge today to design tomorrow's systems. It is now required that the offshore resources industry take cognizance of the existing state of the art, operational expertise established and design capability of the submersible companies in order to provide a useful tool for the subsea environment.

(5) CONTRIBUTION OF LIFE SCIENCES TO UNDERWATER ACTIVITIES:

Underwater activities — physiology

by Surg. Cmdr. D. J. Kidd*

The purpose of this paper is to give a quick review of the physiological problems that face man when exposed to the high pressures and cold temperatures of the waters surrounding Canada and to indicate the targets we should set ourselves and the direction of research effort in this field.

However sophisticated submersibles and remote controlled detection and manipulative devices may become, an adequate substitute for the lone diver using his vision and manual dexterity has yet to be found. It was pointed out forcibly during the recent location and recovery of an H-bomb lost in Spanish waters that human vision was by far and away the most valuable tool in solving underwater salvage problems.

That being so, we must be aware of the interplay of the fundamental limitations of man in this potentially hostile element in order to make best use of his essential contribution.

Exercise

Notwithstanding man's presumed origin from a watery environment, his teleological development has not left him with any pretence of being an aquatic mammal. Man is frankly inefficient at propelling himself through water. The respiratory cost of various physical activities depicted graphically in Figure 1 makes this point. Looked at from an engineering point of view, the efficiency of propulsion expressed as in terms of fuel consumed for velocity achieved, indicates underwater swimming to be an extremely uneconomic process. Some comparisons are given in Figure 2. Under optimum conditions, a highly trained swimmer of Olympic standard can achieve an efficiency of slightly more than 2%. Using swim fins improves efficiency to 6—8%. The additional volume of a modern self-contained life support system increases drag by some 30%. A maximum efficiency of some 3—4% can be expected in fresh water at the temperature of an indoor swimming pool, say, 30°C (86°F). Lower the temperature of the water to say, 0°C (32°F), and increase its salinity to approximate the values found in the Canadian Archipelago and one finds that the kinematic viscosity of the element has increased some 2.4 times; introducing a larger drag term in the power velocity equation. More work is necessary for a given motion through the water.

As will be shown later, increasing depth decreases the work potential.

Lieutenant Commander Lafontaine, one of the two Canadian Forces members with the United States Navy SeaLab III project has described graphically the dis-

*Canadian Forces Institute of Environmental Medicine, Toronto

tress he experienced in swimming with a 600' life support umbilical connecting him to the transfer capsule. The additional d... was "impossible to cope with".

Swimming is hard work and hard physical labour underwater is inefficient and hazardous. Topside planning must always allow for this; underwater vehicles and power tools must do the work.

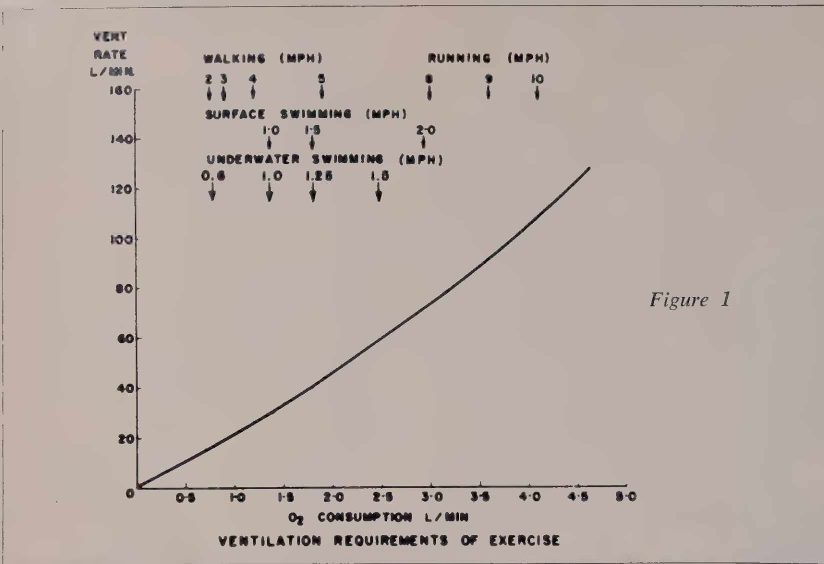


Figure 1

RELATIVE EFFICIENCY EXPRESSED AS PERCENTAGE OF FUEL CONSUMED	
MAN MOVING OVER SOLID GROUND	22 – 41
AIR-WATER INTERFACE	
MODERN CARGO SHIP	20 – 25
SWIMMING, CRAWL	2.5
SWIMMING, BACKSTROKE	1.75
SWIMMING, BREASTSTROKE	1.2
SUBMERGED	
SUBMARINE	35
SWIMMING WITH SWIMFINS	7
SWIMMING WITH SWIMFINS AND SCUBA	2 – 4

Figure 2

OXYGEN TOXICITY THRESHOLD FOR MAN

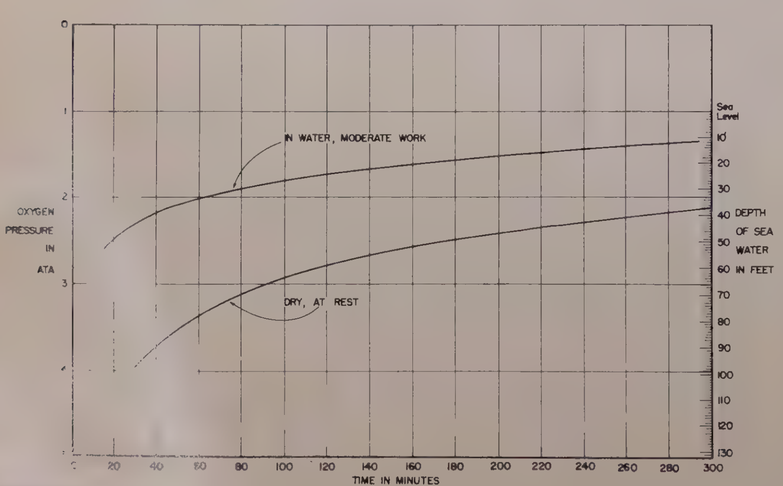


Figure 3

Thermal balance

It is probably not necessary to emphasize that man has an extremely limited range of deep core temperature within which effective cerebration, normal locomotion, and manual dexterity is possible. In water below about 34°C (96°F), nude man will lose heat about 21 times faster than he will in air at the same temperature. The body will respond by producing some extra metabolic heat. Peripheral circulatory changes will reduce conduction losses, but these changes are self-defeating as far as effective performance is concerned. Both reflexes are totally inadequate as time progresses and as the water temperature falls. Cold immersion disturbs respiratory rhythms and can double oxygen requirement. The effect of acclimatisation is small.

The diver must be provided with additional insulation, preferably pressure compensated, to retain integrity of insulation values with depth. As the ambient temperature falls, the number of insulant layers required increases, as does technical complexity. Another solution lies in a combination of additional insulation supplied with external heat from some source, such as heated water circulated between insulation layers as was introduced by the RCN, electrical power or exothermic chemical or physical reactions. All these measures imply greater bulk around the diver or additional tethers, each of which decrease his mobility.

Helium has six times the thermal conductivity of nitrogen. In gas filled compartments such as underwater habitats, transfer capsules or decompression chambers, the environmental temperature must be raised several degrees above that considered appropriate for air at atmospheric pressure to achieve a "comfort zone". Thus, in cold water an even greater temperature gradient must be maintained, demanding increased power for heating. An inadequately heated Personal Transfer Capsule was a contributory cause of the fatal accident that postponed the USN SeaLab III. One would anticipate accelerated heat losses through respiratory exchange when breathing helium. In fact, the property of high thermal conductivity can be turned to advantage by incorporating heat exchanging surfaces in a breathing apparatus, whereby net heat loss is kept at a minimum, lower in effect than can be achieved in the same apparatus using, say, nitrogen as diluent gas.

Limitations imposed by the gases involved in respiration

Oxygen

Oxygen is toxic when breathed at pressures in excess of 0.6 Atmospheres absolute (Ata), the onset and type of toxicity depending upon a combination of the partial pressure of the gas and duration of exposure. Figure 3 gives two time/dose curves for man at rest and when moderately active in the water. Excessive activity (rise in circulating partial pressure of CO_2) and fatigue will shorten the time to reach the threshold of symptoms. Two main symptoms of oxygen toxicity are:

(a) pulmonary damage (evidenced by impairment of ventilatory exchange) following long exposure to partial pres-

sures between 0.6 and 1 Ata.

(b) Central Nervous System excitability and convulsions when partial pressures greater than 1 Ata are breathed.

It is obvious that all symptoms must be avoided. Recovery from a convulsion is rapid if the diver is lucky enough to avoid drowning, choking or bursting his lungs from involuntary depth change during convulsion and he can be switched to a low partial pressure of O_2 quickly. This capacity for rapid recovery is used to prolong the "safe" period when breathing oxygen by cycling the breathing mixture with a high, then a low partial pressure of O_2 and so on, during recompression treatments, and has been considered for operational diving.

To avoid any possibility of oxygen toxicity during dives of long duration, it has been the practice to reduce the inspired partial pressure of oxygen towards the lower end of the "safe" range — 0.21 to 0.6 Ata. Recent work at very high pressures has shown that stratified inhomogeneity in the airways effectively increases diffusion dead space, producing hypoxia in the presence of 0.3 Ata oxygen. One has to balance the risks and select a value for partial pressure of O_2 which will avoid both extremes.

Inert Gas

Oxygen must be diluted with some inert gas. All inert gases have been shown to exert a narcotic effect on the Central Nervous System which is related to molecular weight, solubility in lipids, and partial pressure.

This narcosis becomes subjectively appreciable at 130′ (5 Ata) when breathing compressed air using commercially available SCUBA and 300′ (10 Ata) when breathing compressed air from a bubble (hard hat — "standard" rig), hence the prudent limits given for such activity.

For deeper diving, Hydrogen, Helium and Neon have been used. Hydrogen has 50% of the narcotic potential of nitrogen but has potential explosive hazards. Neon has 27% the narcotic potential of Nitrogen but is too dense for deep diving. Helium is somewhere between 10—23% as narcotic as Nitrogen.

The presence of small amounts of CO_2 greatly enhance the narcotic effect of inert gas. Any circumstance which permits accumulation of CO_2 in the body because of inadequate ventilation or allows CO_2 to be inspired following malfunction of apparatus will provoke symptoms of narcosis varying from confusion and poor judgment to unconsciousness.

Carbon Dioxide

A rise in the tension of CO_2 in the blood is the stimulus to increase ventilation to restore the status quo. It has been shown that the ventilatory response of many divers is less sensitive to CO_2 than non-divers. This is usually compensated by the intentional regulation of depth and frequency of breathing patterns in well trained practised divers, but of course gross failure to compensate will produce respiratory distress and potentiate both oxygen toxicity and inert gas narcosis. Since one of the major keys to safe diving is the adequate elimination of CO_2, physiologists are properly pre-occupied with respiration and airway resistance, and engineers are concerned with improving absorbent canister design and the provision of fail-safe sensors.

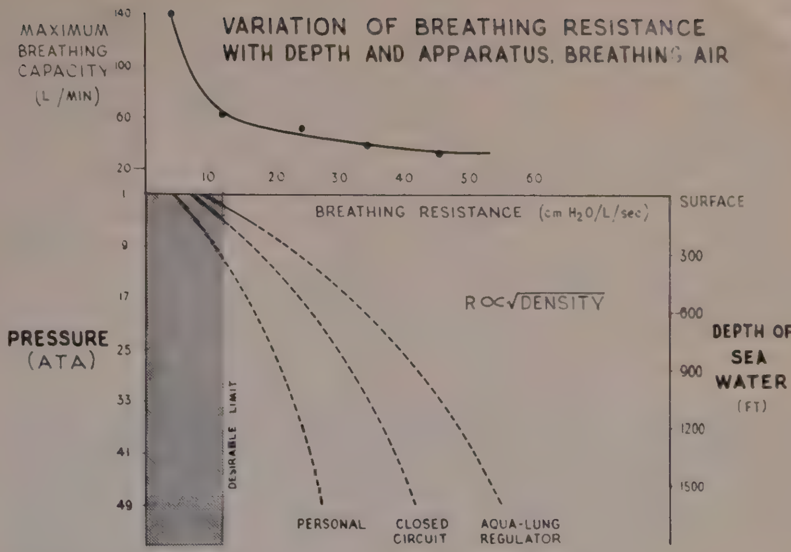


Figure 4

Respiratory Mechanics

The adequacy of respiratory exchange in diving is largely determined by the density of the respired medium. Throughout the range of tidal exchange of practical importance airway resistance varies as the square root of gas density. This relationship between depth and flow resistance is equally true of the external resistances inherent in the geometry of the breathing apparatus used.

Regardless of depth, the same volume of exhaled gas will be required to carry away the CO_2 produced by a given work rate. As depth increases that volume will contain gas at increasing density until a point is reached when even maximum possible ventilation will be inadequate and blood CO_2 will rise. Similarly, the actual work required by respiration itself becomes a large factor and contributes to respiratory muscle fatigue and greater production of CO_2.

Figure 4 shows the effect of combined resistances when breathing compressed air and the depth limitations of high work rates.

Respiratory resistance is plotted against pressure. The solid curves indicate measured values of resistance varying as density down to 300′ (10 Ata) for man's inherent respiratory resistance and the effect of adding resistance due to two classes of underwater breathing apparatus, and the dotted lines show extrapolated values. The upper graph indicates how one measure of ventilatory capacity (maximum breathing capacity) varies with resistance. The desirable limit for breathing resistance is shown by the hatched area. It shows clearly the reason for depth lim-

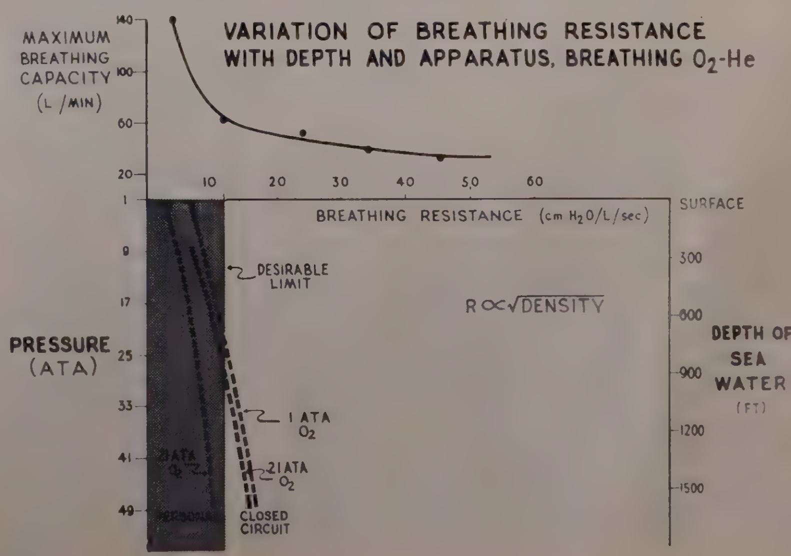


Figure 5

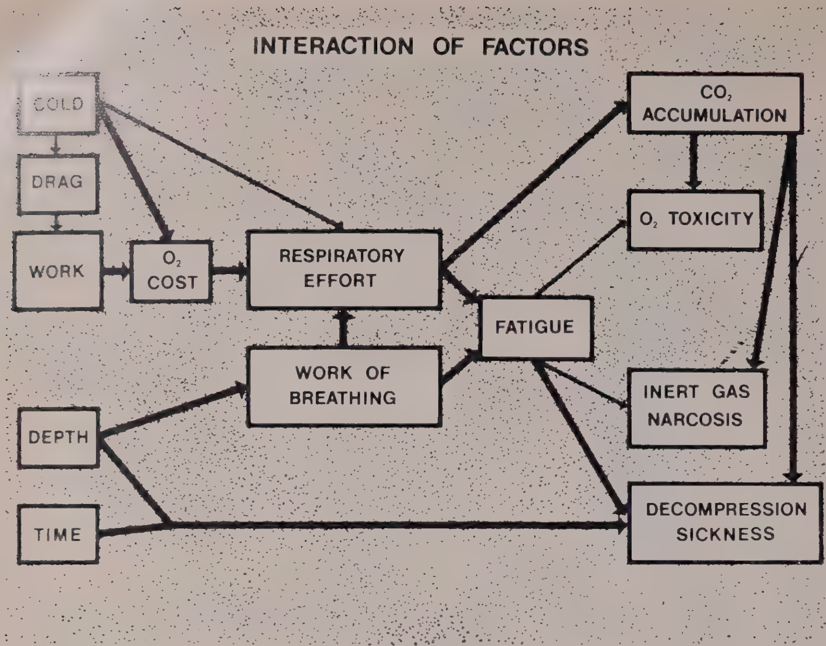


Figure 6

itation breathing compressed air, bearing in mind ventilatory inadequacy alone.

The modification of this picture when helium is substituted for nitrogen is shown in Figure 5.

Two months ago a 3-day residence dive at 980′ (31 Ata) was carried out at Alverstoke, England by three Swiss divers under the direction of Professor Bühlmann, financed by a Dutch Oil Company. During excursions in the water to 1150′ (36 Ata) gentle exercise produced ample biochemical evidence of acidosis or inadequate respiration.

While I have given what appears to be a simple explanation of respiratory mechanical limitations, it is in fact not so simple — the details are complex and by no means worked out.

In brief, the geometry and forces acting on the airways can cause airway collapse during expiration making this phase flow limited. Beyond this point further expiratory effort is wasted, and by the same token assisted exhalation also pointless. We have high hopes that positive-pressure assisted inspiration can provide a longer interval over which expiration can occur, thus partially compensating for the flow limited expiratory phase of the respiratory cycle.

This problem has recently attracted the attention of various groups of respiratory physiologists, notably the groups at McGill and at CFIEM, in a fruitful combined effort. This is a field in which Canada is in the vanguard.

Decompression

The need for prophylactic, or preventative, decompression will continue to be a major economic factor in diving operations — the ratio of cost of total time to useful time on task. In spite of all the research into the physiology of inert gas elimination our methods are still largely empirical.

As far as "excursion" or sub-saturation diving is concerned it is believed that on-line real time analogue computers offer the best solution. In 1963 our group at CFIEM conceived and developed a pneumatic analogue decompression computer which senses the pressure/time profile and offers a continuous and appropriate solution to the diver regardless of the number and configuration of successive exposures. It has a memory, is able to adjust the decompression profile for the inert gas used and offers a flexibility for diving operations within the range tested, not available hitherto.

To give an idea of the relative costs of saturation or residence diving, the decompression profile currently favoured by the USA permits a rate of decompression of about 10 mins per foot of depth. The Swiss and French groups, however, have successfully used rates of ascent following 31 Ata saturation dives of about 5.5 mins per foot of depth. Differences in gas mixtures account for some of this variance.

Current work is directed towards better understanding of the precise mechanisms of inert gas exchange which includes the influence of temperature. Some improvement in efficiency and safety can be achieved by varying the inspired pO_2 and the use of alternate inert gas mixtures.

While adopting these techniques will obviously require more complex life-support equipment, it is hoped that on-line analogue computers can be used to sort out the difficult calculation of decompression debt that will ensue.

The management of cases of decompression sickness has been made more effective and less time consuming using the 100% oxygen low pressure regimes developed over the past five years by the CFIEM, in concert with the USN Experimental Diving Unit in Washington.

For more complicated cases, alternation of inert gas mixtures has been used effectively. The information contained in an analogue computer monitoring Hyperbaric chamber pressure can be invaluable in providing a final decompression solution for an involved case.

The interplay between the factors outlined above is shown in Figure 6.

Other interfaces between physiology and hardware should be mentioned briefly: —

Communications

Verbal communication between divers and between work site and surface has been a continual problem with speech distortion due to changes in the velocity of sound of different inert gas components and density. Much progress has been made with electronic processing of speech to unscramble the spoken word, but the problem has not yet been satisfactorily solved. Transmission of the written word is satisfactory between dry compartments, but other techniques of communication between divers in the water must be explored.

Gas Monitoring

Since the physiological response to respiratory gases and contaminants is generally a function of the partial pressure of the gas, the allowable concentrations become smaller as depth increases. At great depths therefore more sensitive instruments are required for monitoring and control of the environment.

The translation of ideas and concepts from the laboratory or drawing board to actual operational provenance takes time. It is significant that the economic pressures to put working man on the bottom to the limits of the Continental shelf has brought the field laboratory and commercial operators together in an attempt to gain lead time. This sort of inter-disciplinary grouping of experts with traditionally incompatible drives has borne fruit and has demonstrated that the goal is possible and practicable.

There is the lesson for this conference.

Underwater activities — psychology and sociology

by Dr. J. B. MacInnis*

John Glenn, after his historic space voyage, made the following statement: "Whenever man has the means of exploration and discovery, history shows that he has had the courage to make the journey no matter where it might take him."

This comment has relevance to our discussions here today, for we too have the means of exploration, though ours is a different sort of journey . . . a journey into the cold, wet saline embrace of the sea.

Dr. Kidd has outlined for you the medical and physiological hazards that await underwater man. I would like to provide a short outline of his progress beneath the sea, particularly his recent exciting advances. I will also deal with some of the highlights of these advances that I have been personally involved with, and sketch in some of the relevant psychological and sociological implications.

It is sociologically relevant that underwater man has made his greatest progress in this decade. Figure 1 indicates underwater man's depth/time capability up to the year 1960. We can see that most of his activities were in the short-duration/shallow-water area. Figure 2, for comparison, reveals the quantum advances in both time and depth capability that have occurred in the past nine years. This amazing phenomenon is indicative of a world-wide environmental restlessness that has motivated terrestrial man to soar into space and to plunge into the sea. Some of the dives on the chart have had specific sociological significance in that they have introduced mankind to the concept that it is indeed feasible to live and work beneath the sea. These milestones are the SEALAB, CONSHELF and MAN-IN-SEA programs.

Another striking index of man's underwater progress is the number of small submarines now operating around the world beneath the sea. This number has increased enormously too. In 1960 there were two such small submersibles; now there are 50.

We are currently on the edge of a strong surge of underwater activity — commercial, military, scientific and recreational — that places underwater man beneath both the deep and shallow seas. The question arises: "What are the socio-psychological implications of this underwater thrust?"

To try and give a complete answer in a few minutes would be as dangerous as ignoring a decompression obligation — so I would like to try a different approach. I would like to tell you of some recent undersea explorations and expeditions that I have been involved with and what their socio-psychological implications have been to me personally.

For example: Two weeks ago I was totally remote from "Man in Cold Water". It was my privilege to be in the Virgin Islands diving on the Tektite site and into the Tektite habitat. Tektite, as you will recall, was a mission where four men lived for sixty days at fifty feet. The divers were all marine scientists with Ph.D.'s and carried out an exhaustive geological and biological study of the surrounding sea floor and water column. One of the prime sponsors of the mission was NASA

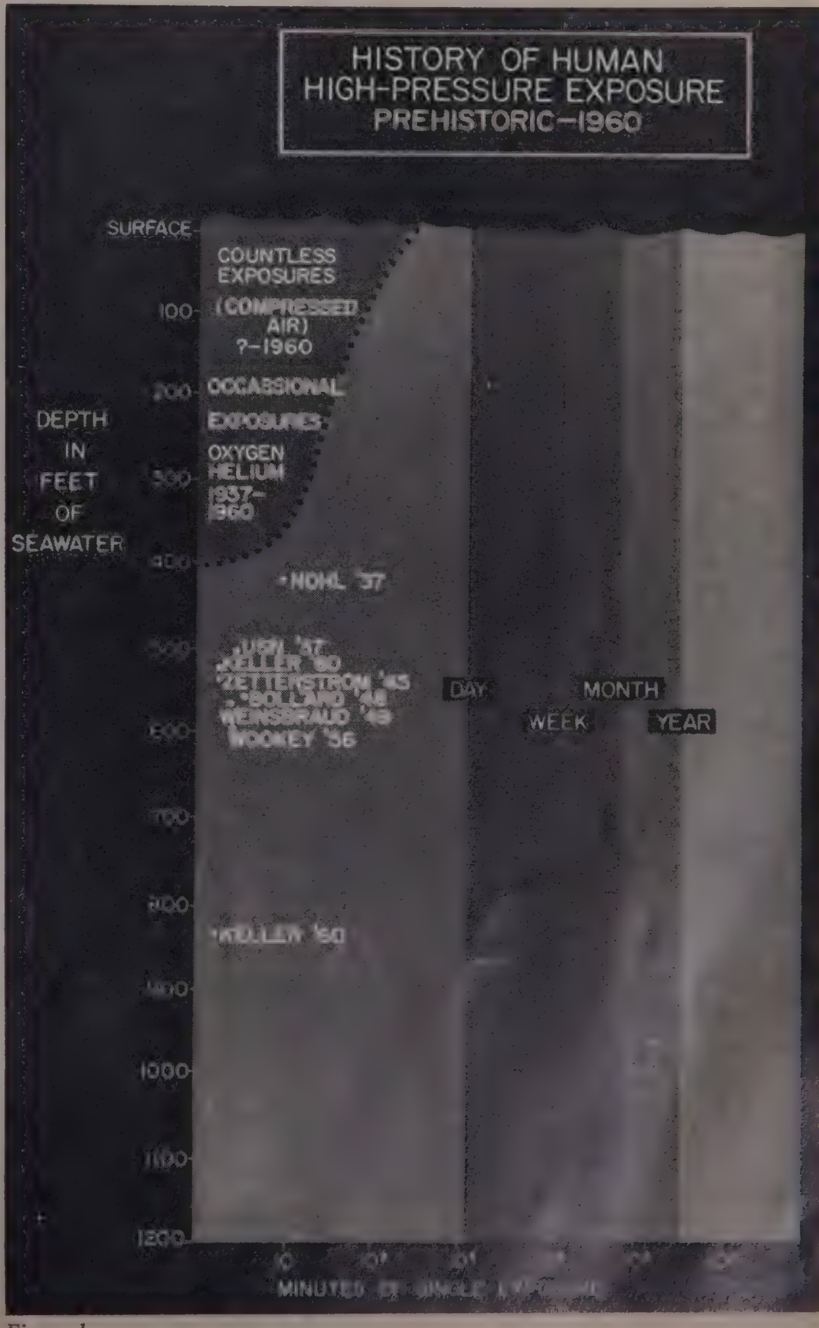
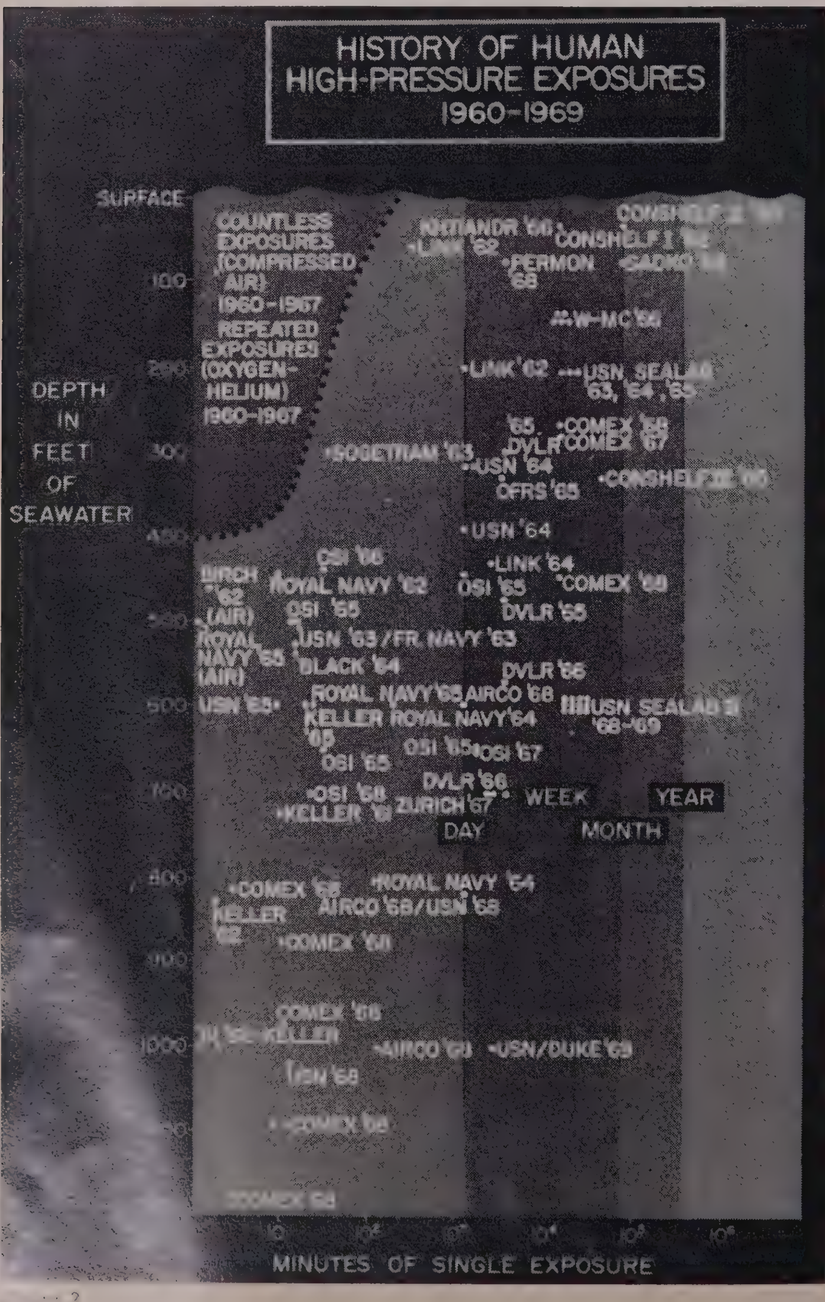


Figure 1

*Medical Director, Ocean Systems Inc.

who was studying the use of the ocean environment to simulate a long-duration space flight. This dive should allow NASA to gather some meaningful psychological isolation data on man. The exhaustive behavioral studies run on the four divers will hopefully be of great value to the space agency as it plans ahead for Apollo Applications and Mars Fly-By missions. Tektite illustrates the actual and potential interaction of many disciplines. It confirms that scientific information recovered from underwater missions has implications that range far beyond the scope of a single environment.

Underwater man has not yet defined his physical or mental limits. This fact has been confirmed three times recently. In England, Dr. Buelman and the Royal Navy at the Royal Navy Physiological Laboratory conducted a multi-day saturation dive to 1,000 feet. Early performance criteria indicate man performs well at these depths, and also well at excursion dives down to 1150 feet. At Duke University in the United States, the experimental diving unit of the U.S. Navy and the Duke University team also conducted a multi-day saturation dive at 1,000 feet. All the biochemical and physiological and performance data again confirmed man's capability to live and work under these conditions. This fact was also confirmed last year when two men descended to a depth of 1190 feet in France. This feat, at COMEX in Marseille, was the deepest simulated dive to date. What I am saying is that we have repeated confirmation of the fantastic adaptability of underwater man. What is also significant is that we just don't know his limits.



Last December it was my privilege to visit the laboratories, also in Marseille, of Jacques Cousteau. An old friend of mine, Prof. Jacques Cousteau, was conducting an experiment that demonstrated that goats, (used frequently in experiments prior to exposing man) can remain healthy and active at depths greater than a half a mile beneath the sea. These goats were slowly pressurized to a final depth of 1,000 meters or 3,280 feet. This is an extraordinary pressure, and although we cannot safely extrapolate from goats to man, the experiment may serve as a rough index of where underwater man may soon live and work. These experiments were sponsored by Jacques Cousteau as part of his overall Conshelf program. In the near future he hopes to conduct experiments that will allow man to live under saturated conditions at depths in the area of two thousand feet. It is interesting that Marseille, an important French city on the Mediterranean and one of the oldest ports in the world, is currently the site of the two deepest simulated-diving chambers in the world. COMEX is building a facility that will go to 4,000 feet of pressure, and CEMA. (Cousteau's group) already have a man-rated chamber that will allow men to remain under pressures of 5,000 feet. It is also interesting that in Canada our deepest research facility goes to a depth of 350 feet (though there are plans for a 1,200-foot facility) and in the United States the deepest research facility planned will only achieve a depth of 2,200 feet.

Underwater man has not, to this date, exhibited any psychological reaction that causes us concern as he lives and works in his new environment. This general topic has been dealt with by Dr. R. Radloff in his new book "Groups under Stress" published by Lippincott, which I highly recommend. However, I had an experience last week which confirms to me that there is still much for us to learn about underwater man. In our 1,000-foot chamber near Buffalo, New York, we ran a research dive to a moderate depth. At 80 feet during the decompression, one of our divers reported decompression sickness. This, in itself, is usually not significant but the follow-on treatment certainly was. Because of problems which developed, and let me say now that none of them were life-threatening, it took us four days and four nights to finally resolve what began as a simple problem. During that time the two divers began to exhibit the classic psychological signs of confinement stress, irritability and close-quartered territorial behavior. This experience emphasizes to me that there are still tremendous investigative strides to be taken.

We are, however, taking those strides. I would like to quickly relate a series of incidents that indicate that underwater man is stretching his mind and his capabilities beneath the sea. I have selected the following experiences because they illustrate the sort of assignments that are now being proposed, and also because

they are particularly related to deep and cold water, which is the theme of this meeting.

In 1967, I travelled with four divers and a submarine pilot to Argentia Bay in Newfoundland. For almost three weeks, under contract to the U.S. Navy and the Canadian government, we conducted a search for a missing classified object on the Grand Banks. Our water depth was slightly in excess of 400 feet but the important thing was the water temperature. On the bottom we were dealing with temperatures of about 40° to 44°F. In 1968, almost the same team was rapidly transported, c/o U.S.A.F., to the Azores where, for three weeks, we were part of the search team for the then missing nuclear submarine *Scorpion*. The water temperature in this area was approximately 50° although the visibility was much clearer than it had been in Newfoundland. Finally, in January of this year, a group of us travelled to Caracas, Venezuela, to salvage the remains of a Pan-American Boeing 707 that had crashed on December 12th. For three weeks, 12 miles off shore, we conducted an extensive closed-circuit television search and then carried out some 21 dives to 370 feet. During these dives we were able to recover major sections of the aircraft, including the flight recorder.

The experience gained on these three occasions clearly showed us how much cold water contributes to the stress arising from deep and prolonged dives, even with the best equipment we have now at our disposal.

It does seem clear that as man's technology expands he will lose more and more expensive objects beneath the 72% of the world's surface that is covered by sea-water. All our underwater capabilities will be called into play in the attempt to recover such objects. [Dr. MacInnis illustrated this point with underwater photographs taken from a small submarine, showing the approach at 300 feet to components of a Nimbus weather satellite whose mission had to be aborted soon after launch from its base in California. He also referred to the need for a bottom search after the crash of a U.S. Air Force aircraft over sea ice off Greenland; in this case the primary search was made by the General Dynamics *Star III* submarine.]

I want to mention two areas which I feel are critical to the overview of social and psychological implications of underwater activities. Both of these areas centre around the word "inspiration". The first concerns the creative potential that will be evoked by underwater man's repeated and prolonged excursions into the underwater environment. The second is the inspiration of adventure that can be instilled in Canadian youth as we embark on our grand underwater explorations.

Let us deal with the first. During the last decade I have watched the evolution of underwater man. I have watched it with great interest because, like all of us here today, I am concerned with the route that we on this spaceship earth are taking towards the future. I have seen much in underwater man's temporary forays into the deep that gives me optimism for the future. I have seen the evolution of an individual who responds to his nonlinear, cold, and horizonless environment in such a way that there is no question in my mind that excursions into the new environment will allow the evocation of new creative potential. It is impossible to dwell within this acoustically and visually enriched environment with its prolonged three dimensional mobility and not come away uninspired. In effect, I am confident that as this new breed of man develops during the years he will find therein the source of much inspirational potential.

Margaret Mead recently made the following statement which seems to summarize the current state of affairs here on earth: She said: "No generation has ever known, experienced and incorporated such rapid changes, watched the sources of power, the means of communication, the definition of humanity, the limits of their explorable universe, the certainties of a known and limited world, the fundamental imperatives of life and death all change before their eyes. They know more about change than any generation has ever known."

I predict that future generations of young Canadians will be part of this change as it relates to the sea. The sea and underwater activities represent a unique opportunity where disciplines must fuse and where the total man with his fullest physical and mental capabilities can truly display his drive. For some reason, as yet unexplained, the sea brings out the creative and poetic potential in people. It is apparent to me that the sea and underwater activities are going to play an increasing role in the psycho-sociological future of Canada and that, perhaps at last, this country will add new meaning to its motto "From Sea To Sea".

Underwater observation techniques in fisheries research

by Dr. J. F. Caddy*

The first aim of fisheries biology is to discover what kinds and amounts of fish are available to fishermen, so that exploitation can be regulated to realize optimum sustained yield. At present, abundance estimates for most species are unreliable, since most methods of sampling fish populations are surface controlled, and often give a misleading impression of the sizes, abundance, and distribution of the species being sampled.

To determine gear efficiency and thus obtain realistic population data, the scientist must ask, "What is the gear doing?" and "How are fish behaving relative to the gear?" Some clues will come from laboratory studies, but eventually we must observe the species in its natural habitat and its reaction to fishing.

Underwater photography and TV are useful here, but have practical drawbacks. Most animals studied by fisheries scientists occur sparsely, or in patches, and directed search is necessary for their location and observation. Television for underwater search is essentially monocular, so that an observer cannot use parallax to gain perspective. Problems of estimating sizes and distances under water make it essential to calibrate a camera before making quantitative observations. Thus, man's presence in the sea is necessary if we are to avoid major misconceptions about our resources and harvesting methods. Our scallop studies illustrate this.

An early preconception was that all scallops in the dredge path were captured, but that small scallops passed through the rings of the bag and back onto the sea floor. We knew that scallops swam to avoid predators, but nobody had investigated swimming and gear avoidance. SCUBA divers accompanying the dredge during fishing saw many scallops swim over the dredge or out of its path (Fig. 1). Comparing dredge catches with SCUBA counts established an overall dredge efficiency of 2%. Swimming, not mesh selection, is evidently the major factor limiting dredge efficiency.

Scallop surveys by SCUBA covered less than 200 sq m per day, working within no decompression limits in 12 fathoms. The Cubmarine covered 5—10 times this area per day, verifying the visual observations by bottom photography. Each scallop observed was recorded by a counting switch onto a chart recorder together with a distance trace provided by a wheel towed along bottom (Fig. 2). This technique has obvious applications for census of other benthic organisms. An important queen crab fishery recently developed in the Gulf of St. Lawrence, although data on distribution and abundance of this species are incomplete. This is also true for po-

*Marine Biologist, Fisheries Research Board of Canada

tentially exploitable animals such as deep sea red crabs, ocean quahaugs, and bar clams which occur on Canadian grounds.

Preliminary experience of collecting animals from submersibles suggests that mechanical manipulators must be considerably improved before they can approach the manual dexterity of a diver. Quantitative sampling of rapidly moving lobsters or gelatinous masses of herring spawn can only be accomplished by divers. A lock-out submersible such as Shelf Diver (Fig. 3) combines the mobility and endurance of a submersible with a diver's versatility and could be used to survey herring spawning areas. An estimate of the extent and density of spawning beds may enable us to predict future abundance of herring. Herring spawn on bottom in less than 6 fathoms in the Gulf of St. Lawrence, and 6-30 fathoms in the Bay of Fundy. Spawning beds in the Gulf were surveyed by SCUBA. To work successfully in the Bay of Fundy, divers will need a lock-out submersible to take quantitative spawn samples.

Studies of lobster populations and the colonization of artificial reefs have been successfully carried out by SCUBA in less than 12 fathoms in the Gulf of St. Lawrence. A lock-out submersible would greatly assist studies of these Crustacea in deeper water, since lobsters often occupy burrows and cannot be surveyed by visual methods alone.

Hydrographic and plankton sampling during under-ice crossings of the Arctic Ocean by the nuclear submarine SEA DRAGON gave us our first synoptic knowledge of the distribution of Arctic plankton.

In situ observations are also invaluable for the study of pelagic and planktonic animals. Direct observations on the deep scattering layer from submersibles SOUCOUPE and ALVIN have given us first-hand knowledge of the organisms responsible for this sound reflecting phenomenon.

Direct observations on mid-water fish present greater problems. Fish such as herring, cod and haddock were rarely observed from the Cubmarine, although present in the operating area. This may partly have resulted from the limited visibility (about 10 ft) in Canadian inshore waters, but larger fish also seemed to avoid the moving submersible. Reaction distances of fish to sound generated by a moving submersible would only have to exceed 10 feet for them not to be seen under these conditions. Even with good visibility, counting of fast-moving fish is difficult.

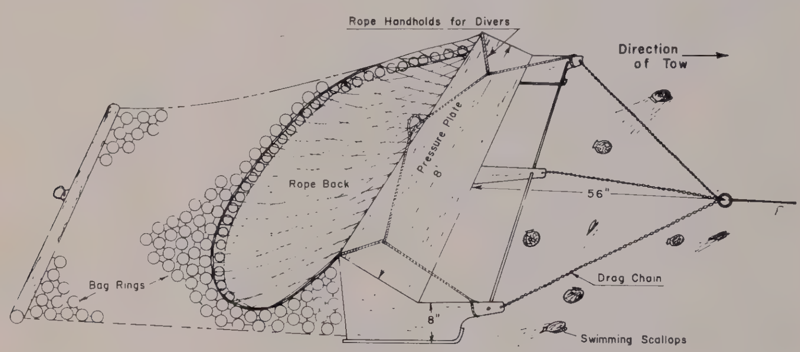
The only successful observations on cod were made with the Cubmarine sitting on bottom. Bait scattered on bottom around the submersible attracted cod, flounders, lobsters and rock crabs, and feeding behaviour and social interractions could be studied. This method should yield valuable information on performance of traps, longlines and chemical attractants.

The low speed of most self-propelled submersibles suggests that fish behaviour and trawl performance will be most successfully studied from towed submersibles such as the ATLANT used by Russian fisheries scientists. Side-scanning sonar promises to be the most practical method for fish census and has been successfully used from surface vessels. Problems of species identification are not fully resolved, and the method has limitations for bottom-dwelling fish. The Russian fisheries submarine SEVERYANKA has shown that sonar counting of fish from a submersible can be combined with visual verification of the species being counted.

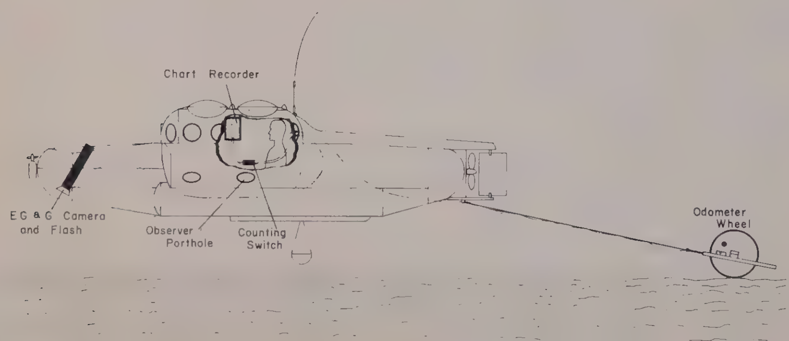
A major area where underwater techniques are becoming important is marine pollution. SCUBA surveys in the English Channel following the Torrey Canyon disaster showed that most organisms were more affected by the detergent used to remove the oil slicks than by the oil itself. Early attention to problems of marine pollution should help prevent the biological catastrophe which occurred in the Great Lakes from recurring in Canadian territorial waters.

In conclusion, man's presence in the sea is needed to overcome limitations to our understanding of biological phenomena imposed by present remote sampling methods. Perhaps the first role of the underwear biologist will be the calibration and improvement of conventional sampling techniques. Ultimately, however, the development of new underwater techniques will lead to man's working presence in the sea. This will be essential to any rational management of our offshore biological resources.

1



2



3

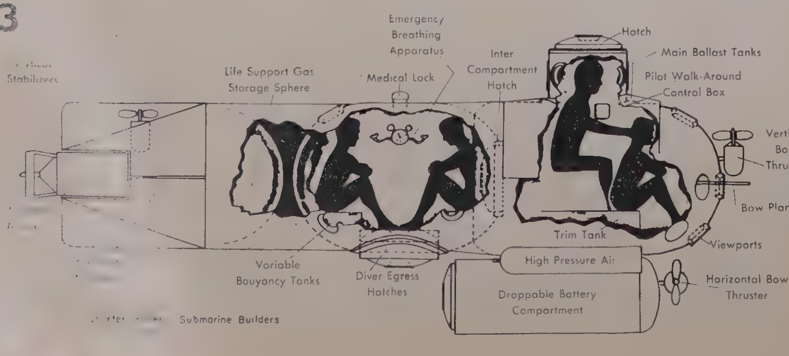


Fig. 1. Eight-foot offshore scallop drag modified to allow divers to accompany it during fishing.

Fig. 2. Diagrammatic representation of equipment used with Perry Cubmarine PC3B during scallop survey work.

Fig. 3. Shelf Diver: a submersible with diver lock-out facility.

Physical oceanography in Canadian Arctic

by Dr. Ola M. Johannessen*

Introduction

In this talk some aspects of physical oceanography in the Canadian Arctic will be dealt with. In the northern part of the Archipelago, a permanent ice cover is present year round and during part of the year the ice cover is landfast, and little movement takes place. However, going southward more variable ice conditions exist and the ice can even move during winter time. In areas such as Baffin Bay, Hudson Bay and the Gulf of St. Lawrence the ice disappears entirely during the warmer period of the year. Therefore, in the Canadian Arctic we have to deal with three principal conditions:

1. Ice free condition
2. Drifting ice cover
3. Landfast ice cover

The presence of an ice cover will in general dampen out wind generated mixing process, reduce the amplitude of the surface waves drastically and modify the tidal and current regime.

The distribution of land and sea in the Archipelago makes it very difficult to formulate theoretical models from where the ice water circulation can be derived, and no realistic model so far has been published for the Canadian Archipelago. The approach to understand the oceanography has been derived from observation of oceanographical and meteorological parameters during summer time; however, very little is known about the winter condition. Numerous papers have been published on the physical oceanography, and it is not relevant here to mention all the important contributions. An excellent review paper was published by Collin and Dunbar 1964 (A. E. Collin and M. J. Dunbar, Oceanogr. Mar. Biol. Ann. Rev., 1964, 2: 45-75, Harold Barnes, Ed., Publ. George Allen and Unwin Ltd. London) and the interested readers are referred to this publication. A summary of the published results will be given here and in addition some aspect of the Ice Drift Studies by our group at McGill University in the Gulf of St. Lawrence will be commented on.

Bathymetry

The depth of the Shelf, which of course is the most important for industrial purposes, in the Western Arctic is around 550 meters with a width of a few miles off Northern Ellesmere Island to over 100 miles in the Beaufort Sea. In the eastern Arctic, in contrast, the depth of the continental shelf is about 200 meters with a width of seldom more than 30 miles. The internal areas in the Archipelago are generally shallower than the coastal shelves, apart from areas such as Jones Sound, Lancaster Sound and Hudson Bay in the eastern passages. However, in the western areas the depth is comparable to the coastal shelf. The depth of water in the Archipelago varies from 550 to less than 100 meters in Barrow Strait, where a threshold depth of 150 meters is also found. The bathymetry influences the circulation and particularly the exchange of the deeper water. In Smith Sound, the threshold depth is about 200 meters, and the limiting depth between Baffin Bay and Labrador Sea is about 730 meters.

Tide

The tide in the Canadian Arctic is of semi-diurnal and mixed semi-diurnal type. The observations, analysing and prediction of the tide is carried out by the Hydrographic Service, Department of Energy, Mines and Resources in Ottawa. The tides in the Canadian show tremendous variation in range as regard to geographical locations. Typically, off the Northern Baffin Island an amphidromic point is located where the tidal elevation approaches zero. Southwards the tide increases to 6-7 meters in the entrance to Frobisher Bay and Hudson Strait area. Northwards the tide increases in range to 3 meters in Smith Sound and thereafter decreases to less than 0.5 meters off the Northern Ellesmere Island.

Water masses and stratification

The water masses in the Archipelago is a mixture of water from the Arctic Ocean and the Baffin Bay. The exchange of deeper water is limited due to the threshold depth in Barrow Strait and Smith Sound. During spring summer melting there occurs a brackish surface layer overlaying the more saline water below. In general a sharp boundary exists between these two layers and the water below the boundary is much heavier than the surface layer. Physically this means that it is difficult to mix the two layers and the stratification will play a very important part as regards to pollution of e.g. oil spill. During autumn and early winter reduced run off and cooling with formation of an ice cover results in decreasing stratification and vertical convection can take place. In the Archipelago, vertical convection down to 50 meters can occur.

Circulation

The coastal current off the northern coast is part of the Beaufort Gyral, with a low speed of about 5 cm/s or 1/10 knots. In some of the narrow straits the average speed increased to one knot, but in parts of the area the tidal current is much stronger. Generally there is a net transport of water from the Arctic Ocean through the Canadian Archipelago and Smith Sound, in the order of 1-2 mill m^3/sec (this unit is often called a Sverdrup).

Ice Drift

Knowledge of ice conditions, distribution and drift is particularly important in the Canadian Arctic, and investigations in these fields may help to formulate better prediction models for improved navigation.

In the Archipelago, very little is known of the drift, and the same can be said, to some extent, about the Gulf of St. Lawrence. When investigating ice drift, it is not enough just to observe the drift, but it is essential to look at the whole system — lower atmosphere, ice and water. An ice field is under the influence of the following forces:

1. Wind stress
2. Water stress
3. Coriolis force (due to rotation of the earth)
4. Pressure gradient force
5. Tidal force
6. Internal ice stress

The force we know least about, and the most important one with regard to transportation, is the internal ice stress. The effect of internal ice stress is that several floes jam together, due to, for example, a convergent wind field, resulting in pressure ridges being formed.

At present our group at Marine Sciences Centre, in cooperation with governmental agencies, is investigating the ice drift in the Gulf of St. Lawrence, both from an experimental and theoretical point. In 1967 an unmanned buoy equipped with radio beacon was set out on an ice floe off the Gaspé coast and tracked by D.O.T. ice reconnaissance plane during a three-week period. In 1968, a "Manned Drifting" station drifted through the Gaspé passage, 150 nautical miles during a six-day observation period. The maximum distance travelled in one day was 35 nautical miles. The floe took part in the tidal motion, and the response time due to changing wind stress was in the order of 2-3 hours. During the winter 1969, a sealer was located in an ice field. The program was to measure wind stress, current at different levels, oceanographic stations and a first attempt was made to investigate the internal ice stress by setting out large reflectors on the ice and track them with radar. (J. Keys, D.R.B.)

Summary

In this lecture I have tried to give you some information about our knowledge of the Canadian Arctic, and what the problems are. The exploratory investigations have just been finished, and it is now time to start a systematic investigation over the whole year, using some of the new ideas of modern undersea technology.

*Asst. Prof. Physical Oceanography, McGill University

THE ICE COVER — occurrence, thickness and mobility

by Dr. M. P. Langleben* and Dr. E. R. Pounder*

Introduction

Sea ice covers a surface area greater than 16 million km² in the northern hemisphere during the winter. The ice cover decreases somewhat in extent in the summer when ice melts completely in the sub-Arctic regions and to a slight degree in the Arctic Basin. In these waters, almost any operation which is undertaken is vitally influenced by the presence of the ice cover. This is true equally, for example, of an ocean cable-laying operation in the Maritime Provinces where sea ice may be troublesome for only part of the year, for offshore drilling operations along the continental shelf and for an attempt to navigate the North-West Passage where the ice cover is much more persistent.

Considerable interest is being paid at the moment to the North-West Passage. Attention has been focused on this area by the proposed plan of the 150,000 ton experimental tanker/icebreaker Manhattan to run through Parry Channel later this summer. The route will take the ship from the east through Davis Strait, Baffin Bay, Lancaster Sound, Barrow Strait, Viscount Melville Sound and then either north of Banks Island through the McClure Strait into the Beaufort Sea, or west of Banks Island through Prince of Wales Strait into Amundsen Sea and then Beaufort Sea. If this venture is successful, the traffic of even larger tankers through this passage is likely to become commonplace over the next few years.

The logistics of planning operations in ice-infested waters and of carrying them to a satisfactory conclusion require detailed information on the extent, thickness and seasonal variation of the ice, of its movement, and of the pressures it can exert against structures such as ships and piles. It is the purpose of this paper to review briefly the present state of knowledge in these areas.

Occurrence and thickness

The ice cover at any given time is not homogeneous, even when viewed on a local scale. It may consist of ice of varying thicknesses and, in the Arctic, of varying age. One is likely to encounter thin newly-refrozen leads, first year growth of considerable thickness (winter ice), rafted ice, pressure ridges and, in the Arctic, polar pack ice which may be several years old.

Observations on ice thickness have been made for more than ten years at weekly intervals at more than 50 locations throughout Canada, Alaska and Greenland. Dates of freeze-up of open water and of break-up at the same sites also have been recorded. This information is available in a series of annual publications of the Meteorological Branch (*Ice thickness data for Canadian selected stations, freeze up 196- to break-up 196-*, Department of Transport, Canada) and in several reports by M. A. Bilello (*Ice thickness observations, North American Arctic and subArctic*, U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) Special Report 43, Part I (1961), II (1964), III (1966)). The following table gives the mean maximum thickness of one year ice (winter ice) for a number of sites in the sub-Arctic and Arctic, and the approximate dates of freeze-up and break-up. Typical values of the thickness of the polar pack in the Canadian Archipelago and the Arctic Basin also are included.

Location	Max. thickness	Freeze-up	Break-up
Gulf of St. Lawrence (North shore, Chaleur Bay)	3 ft	early-Jan.	late-March
Labrador (Hopedale)	3 ft	mid-Dec.	early-May
Hudson Bay (Churchill)	5 ft	mid-October	June
Eastern Can. Arctic (Alert, Resolute, Hall Beach)	7 ft	late-Sept.	mid-July
Western Can. Arctic (Tuktoyaktuk, Coppermine, Cape Parry)	6 ft	late-Sept.	mid-July
Can. Archipelago, **Pack Ice**	8 ½ ft	**Pressure Ridges**	
			Height 12 ft
Arctic Basin, **Pack Ice**	12 ft		Depth 50 ft

It is rather difficult to set representative values for pressure ridges which are extremely variable in height and in distribution. The figures quoted in the table, a height of 12 ft and an immersion of 50 ft, are not uncommon. These ridges are formed in areas of the ice pack which are in a state of convergence. They severely limit the operation of over-ice vehicles and are of some concern to underwater vehicles as well.

Ice distribution

The strength of sea ice varies, amongst other things, with its age. For example, an icebreaker may be able to make steady headway through 5 ft of first year ice and yet run into difficulty in pack ice of the same thickness. It is essential therefore that the proportion of each type of ice and its distribution be known, as well as the total extent of the ice cover.

Such data have been acquired by the Meteorological Branch which has been conducting regular ice reconnaissance flights (and an ice forecasting program) in support of shipping in Canadian ice-infested waters for the last ten years, and by the U.S. Navy Hydrographic Office. The Meteorological Branch has been publishing this information as annual reports in two series; one on ice observations (e.g. *Ice observations, Canadian Arctic, 1964*, Department of Transport, Canada) and the other as summaries (e.g. *Ice summary and analysis, Canadian Arctic, 1694*, Department of Transport, Canada).

The latter series presents the progress of break-up through a set of ice charts at seven or fourteen day intervals through the summer, accompanied by brief descriptive text and surface pressure maps and temperatures. The ice charts delineate the extent of the ice cover and use a variety of types of hatching to indicate the concentration of ice (in tenths) in a given area, and colours to indicate the proportions of young, winter and pack ice. Optimum ice conditions for shipping usually occur towards the end of August when Davis Strait, Baffin Bay and Lancaster Sound are relatively ice-free and there is a lot of open water in the seas off the mainland of Alaska and Canada. However McClure Strait and the western part of Parry Channel still retain about nine-tenths ice cover at this time of year.

Ice movement

Indications are that there is very little shore-fast ice in the Canadian Arctic except in the many fiords and small sheltered bays. The rest of the ice cover moves about under the influence of local currents and winds even in mid-winter. The study of the factors influencing the drift of ice has assumed a high priority recently, amongst them the study of internal stress in the ice pack which is caused by convergence. Observation data on the relevant meteorological, physical and oceanographic parameters are required badly. The McGill group has become involved in these problems in the Gulf of St. Lawrence and other groups are working in the Arctic.

Some information about ice drift in the Arctic Ocean has accumulated over the years, starting in 1893 with the voyage of the Fram which was frozen into the ice pack and drifted with it for about 3 years. More recently, drift observations have been made from both Russian and American-manned ice-islands. Although the data are scanty, some general drift

*Professors of Physics, Ice Research Project,
Department of Physics,
McGill University

patterns emerge. The main features of ice drift within the Arctic Ocean are:

(a) a strong broad transpolar drift stream from the East Siberian Sea to the Greenland Sea which acts as the main discharge for ice from the Arctic. Mean annual drift rates vary from about 0.2 to 2.5 nautical miles per day and short-term drift rates are much more variable in magnitude and direction.

(b) the Beaufort Gyre, a clockwise circulation resulting from the predominant atmospheric high pressure in this area with consequent anticyclonic wind pattern. Ice near the edge of the gyre can escape into the central stream but, nearer the centre, it may circulate for many years. For example, the ice-island T-3 which was occupied in 1952 has completed two circuits of the gyre to date. Drift rates inside the gyre are highly irregular but lower than in the main stream.

Little is known about drift among the Canadian Islands. There is no doubt that some of the ice from the Arctic Ocean finds its way through the channels of the Canadian Archipelago and escapes to the south-east. Several short-term drift rates have been reported of magnitude comparable to the highest in the Arctic Ocean but mean drift rates are expected to be very low.

Underwater acoustics in ice-covered seas

by A. Milne*

Many of the factors which control the utility of sound waves for communication under water are directly controlled by the state of the surface weather. In open oceans the upper surface is in contact with the moving air which creates wind-waves, drives ocean currents and intimately affects the water temperature and salinity. In the Arctic the surface weather creates the ice, forms the pressure ridges, and in some ways can drastically alter the conditions under which sound waves can propagate. Nevertheless, the water in Arctic regions, compared to the atmosphere, remains a relatively warm and hospitable medium which will be used in the future for submarine transportation. At times, the ice will inhibit access to the atmosphere for communication and navigation and under these conditions, underwater sound will be the best way of conveying information underwater in the use of navigation and tracking sonars, polynya and iceberg detectors, pingers and transponders. It is therefore important to know the behaviour of sound in Arctic water, what information on this behaviour is now available and what is currently missing.

First, a look at sound in water:

Sound waves in sea-water travel roughly at a speed of 1500 m/sec, which is about 4½ times the speed of sound in air. This speed is not quite constant and increases with the water pressure, temperature and, to a small degree with salinity. Sea water is not uniformly mixed so that sound waves travelling through it will bend, or refract, much as light upward because of the dominant effect of increasing pressure with depth.

By the use of pulsed sound sources, echoes and reverberation can be displayed on a time-base. The time between the outgoing pulse and the reception of the echo gives a measure of distance. A directional sound source will add azimuth information so that a radar type of PPI display can be formed. Unfortunately, compared to radar the information rate for a similar geometry is down by a factor of 2 x 10^5. Target definition requires the use of short wavelengths but again unfortunately, the attenuation of underwater sound increases with the frequency squared. For example, if we consider the attentuation at a low frequency of 5 kHz, where the wavelength is 30 cm, the attenuation loss is only 4% per km, but at 60 kHz where

*Physicist, Defence Research Establishment Pacific, Defence Research Board of Canada, Victoria, B.C.

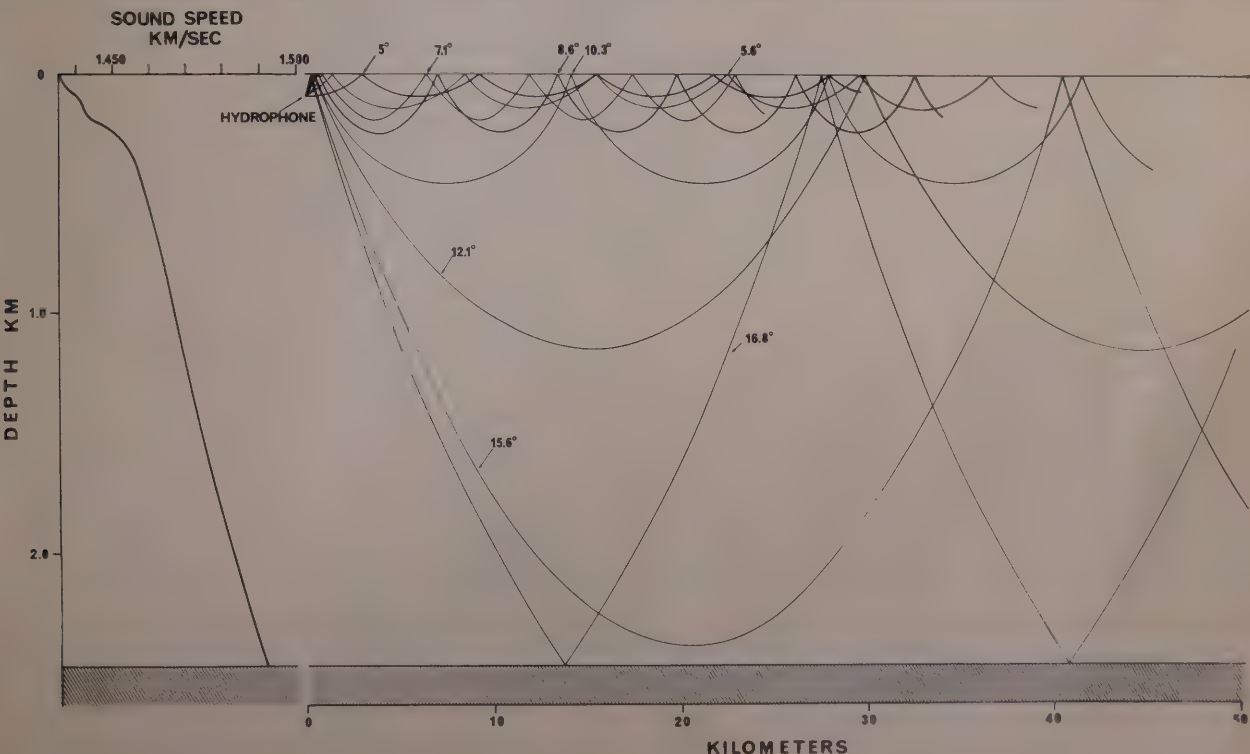


Figure 1. The speed of the sound vs depth in the Arctic Ocean and its effect on underwater sound ray paths.

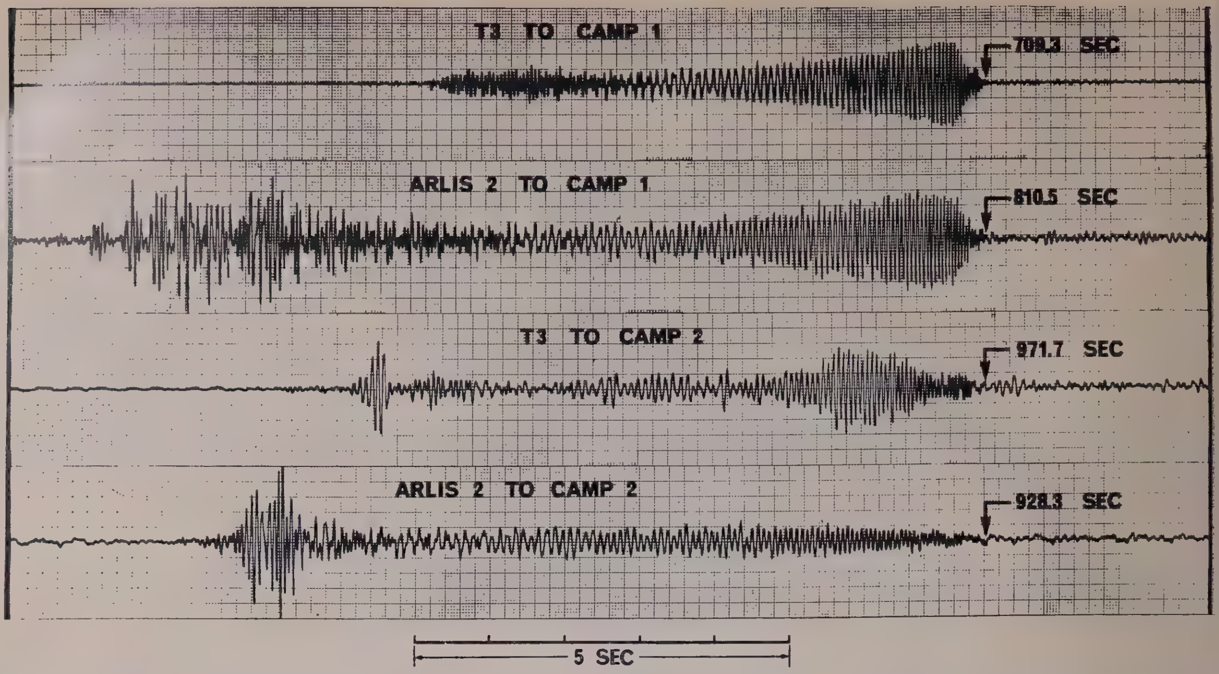
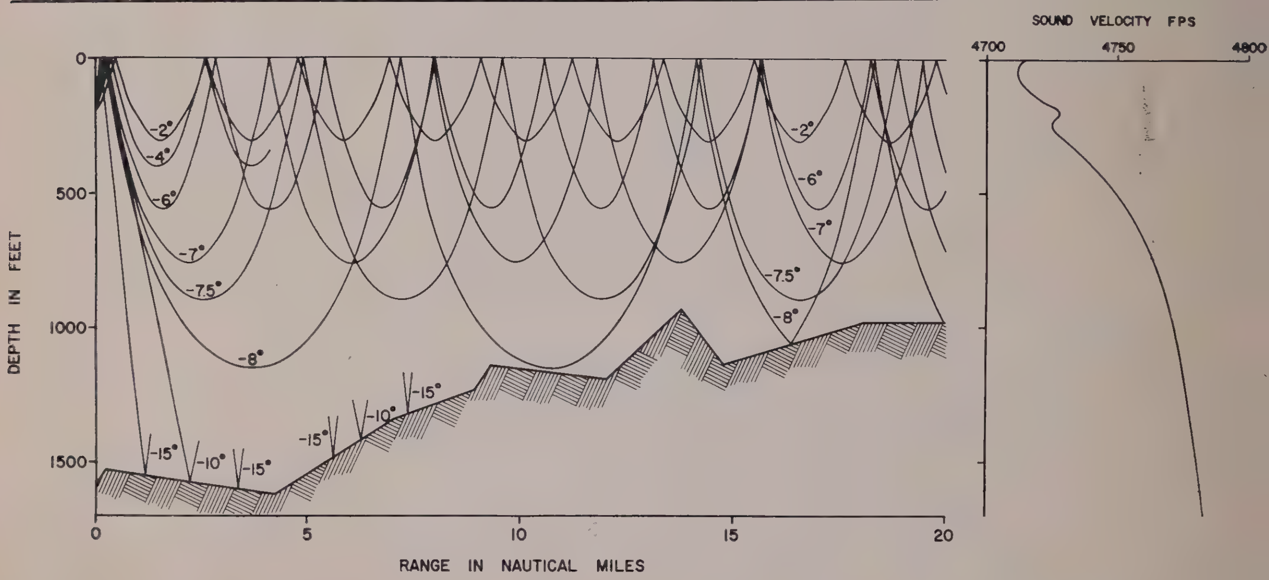
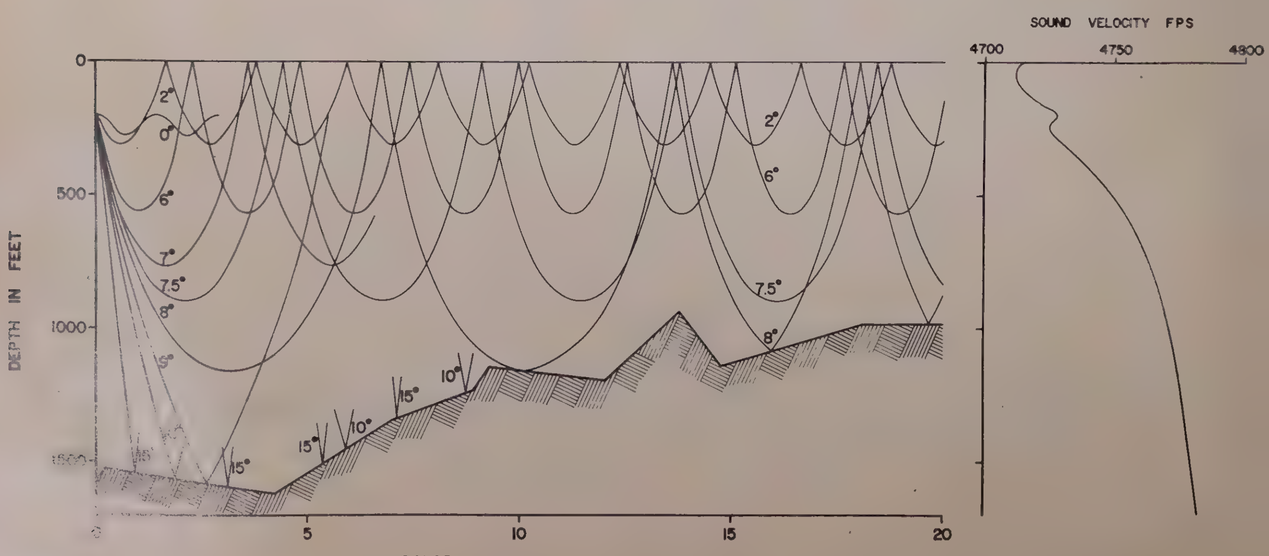


Figure 2. The dispersion in time of sound waves from explosive sources after travelling over long paths in the Arctic Ocean; B12, 1000 kms; A15, 1200 kms; B16, 1450 kms; and A19, 1380 kms.





Some underwater sound paths in Prince Gustaf Adolph Sea, west of Ellef Ringnes Island.

the wavelength is 3.5 cm, the attenuation loss is 90% per km. It can be seen that sonars become quite short-sighted at high frequencies, and require high pulsed power levels to overcome transmission losses.

The paths of a sound-pulse underwater are further complicated by being squeezed between a surface covered with ice and a bottom often not too far below. Because the sound-waves must bend upward, the depth of water will determine the maximum horizontal distance a sound-wave will travel before either a surface or bottom reflection occurs. Figure 1 illustrates this last comment. The left hand side shows a curve of the speed of sound in km/sec, plotted against the depth of water in the Arctic Ocean. On the right hand side are plotted a few ray-paths, on a compressed horizontal scale, for sound waves which we imagine as emanating from the point called 'hydrophone'. It is seen that a single pulse of sound will have its wave front spatially modified so that some parts of it will undergo bending, or refraction, in the water column and reflect one or more times from under the ice. Energy which plunges deeper will reflect from the bottom as well. All these paths result in a different sound-speed referred to the horizontal direction so that a single pulse of sound will be geometrically dispersed into a complicated wave train when observed at long ranges.

Another serious complication exists. The ice canopy is very rough. If one could move along the underside of pack ice and be able to trace the roughness amplitude, the resulting "noise" would have a rms amplitude of between 2 and 3 meters. The roughness waveform would also be somewhat impulsive. Peak roughness would range to near 50 meters at pressure ridges. In contrast, areas covered solely by annual ice have peak to peak roughnesses which do not appear to exceed 0.3 meters. When a sound wave reflects from under the rough pack ice, there will be wavelets scattered away from the direction of the specular reflection defined by the reflected ray path. This scattered sound energy is generally lost or causes unwanted reverberation noise.

For subsonic frequencies, 50 Hz and lower, the scale size of the under-ice topography is smaller than a sound wavelength so that there is little scattering and the rough ice looks like a plane surface. For increasing acoustic frequencies the scattered sound energy begins to exceed the desired specularly reflected energy until at frequencies above 400 Hz, the specularly reflected intensity averages only 1/10th the incident. Consequently only very low frequency sound waves appear at long ranges under sea-ice and they exhibit a complex waveform on account of the geometric time dispersion previously described. Figure 2 shows some examples of the fate of sharp explosive sounds after travelling over distances of approximately 1000 kms, 1200 kms, 1450 kms and 1380 kms in the Arctic Ocean.

For navigational and search sonars as well as for pingers, transponders and underwater voice communications we must use frequencies well above 400 Hz in order to reduce equipment sizes and weights and to maintain definition. Consequently, under sea-ice we will almost always have to define the operating ranges of equipments as limited to the maximum distance the sound can travel between the two points of interest without reflecting from the ice canopy. This distance can be described by the "horizontal reach" of the bottom-limited ray. For a particular depth of water this ray will bend back up toward the surface without going quite deep enough to reflect from the bottom.

The ray diagram, in Figure 3, again with an exaggerated depth dimension, applies to Prince Gustaf Adolph Sea in the springtime and shows that the surface-to-surface distance for a bottom-limited ray will not exceed 8 miles in a water depth of 1200 ft.

I have covered some aspects of sound transmission under sea-ice, but one may very well ask "Why not increase the sound power output and also use more sensitive receivers?" Here we encounter the problems of reverberation and the ambient background noise. Reverberation is the sum of all the sounds from scattering in the environment which produce a time-dependent noise in the receiver. The intensity of reverberation, which is the sum

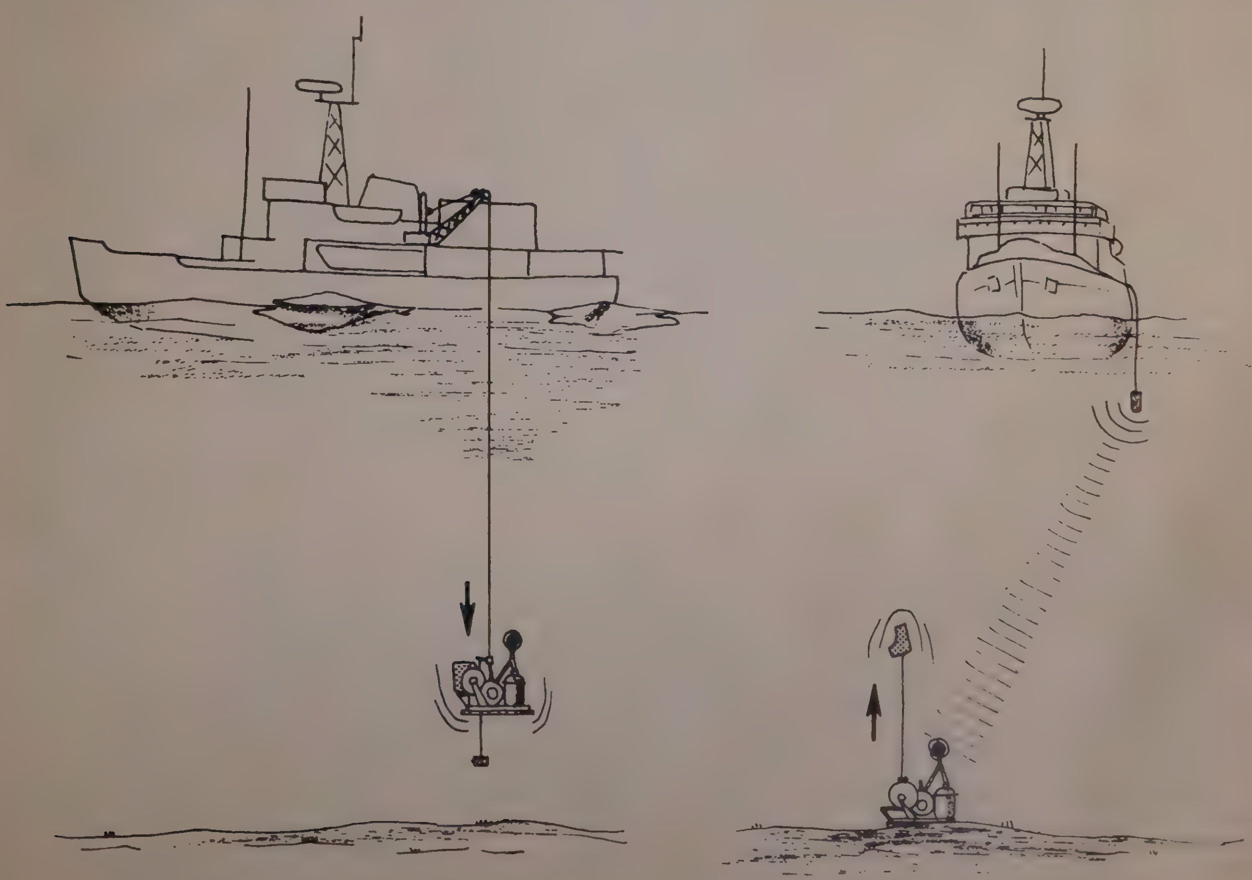


Figure 4. Method of installation and recovery, one year later, of an RIP used for recording underwater noise spectra.

Figure 5. Locations where five RIP's were set on the sea-bottom during August 1967. All except the most easterly unit, in northern Baffin Bay, were recovered in August 1968.

of all false target echoes, keeps step with the intensity of the wanted echo and increases directly with the sound power output. Rough pack ice forms a strong reverberating surface, at least for frequencies above 400 Hz. Reverberation from pack ice is similar in magnitude to that observed in ice-free seas with a 40 knot wind blowing. There is one major difference. The ice roughness is not changing rapidly like an undulating sea-surface; and where it is shorefast during the winter and springtime in the Archipelago, it is virtually motionless. Since the bottom is also motionless there is a possibility of developing sonar systems which cancel out the fixed, phase-coherent reverberation and look for movement.

For high acoustic frequencies, 30 kHz and above, there are only a few inconclusive measurements of the strength of reverberation from sea-ice and these have been made only when logistics have defined the seasonal window. Such measurements throughout all seasonal ice conditions and types are a pressing requirement to remove the guesswork in the design of upward looking echo sounders, under-water voice communication systems, side-scan sonars and even for torpedo sonars. There may very well be conditions in the growth or decay of sea-ice where it becomes a good acoustic absorber.

I have mentioned the natural background noise [illegible] another limitation to the [illegible] one might obtain by increasing [illegible] sensitivity of underwater sound receiv- [illegible] ice covered Arctic seas are very special in that nearly all the ambient noise is generated by the ice itself. The sea ice prevents surface wave motion and as a result, Artic seas are, at times, the quietest on earth. The quiet times occur most frequently in late April and May when there is no wind and the ice surface is slowly warming and is unbroken. At other times the ice produces noise which can interfere with the detection of desired signals. In the winter and early springtime, the surface of the ice responds to changes in heating and cooling. A drop in air temperature causes shallow surface cracks. This cracking produces impulsive noise in the water. Another type of noise is produced by wind flowing over the surface of the ice. Still another is produced by the motion of floes in the late summer and fall when the relatively delicate new ice is unable to resist the floe motion.

There is a large amount of information available on ambient under-ice noise, mostly obtained by the Defence Research Establishment Pacific. In particular, a vast amount was obtained last summer when four "RIP" units were recovered from the Archipelago using the icebreaker CCGS LABRADOR. Each RIP was designed to record the underwater noise spectrum on digital magnetic tape each hour for a year while unattended.

The sketch on the left hand side of Figure 4 shows an RIP being lowered to the sea bottom. The right hand side shows the RIP being acoustically interrogated one year later. Upon sensing the correctly coded sounds, an explosive bolt permitted a subsurface float to rise to the surface. At the surface the float ejected a dye marker and transmitted a radio homing signal. Recovery was achieved by reeling a wire rope from a submerged cable reel onto the ship's winch.

The map in Figure 5 shows the locations where RIP's were installed in August 1967. All were recovered successfully in August 1968, except for the unit in northern Baffin Bay. This RIP was crushed by a large iceberg aground in 1400 feet of water on the installation site.

One outstanding characteristic of the noise is its variability with time. This feature is clearly shown in some preliminary results from the RIP unit recovered south of Melville Island. Figure 6 shows three pieces of a strip chart record of noise in the 150-300 Hz band. The vertical scale, on each, is the noise intensity in dB and represents a change from a factor of unity to 10^5 (or 50 dB). The upper strip is 7 days worth from October; the centre strip is for 7 days during January and the lower strip is for 7 days during April. The envelope of the noise intensity is formed by the hourly samples. A point I wish to make is that the character of the noise envelope is directly related to the state of the ice canopy and to the surface weather.

The RIP units were specially designed to cover sonar search frequencies and frequencies for passive detection systems and therefore obtained information up to 16 kHz only. There is extremely little under-ice noise information available for fre-

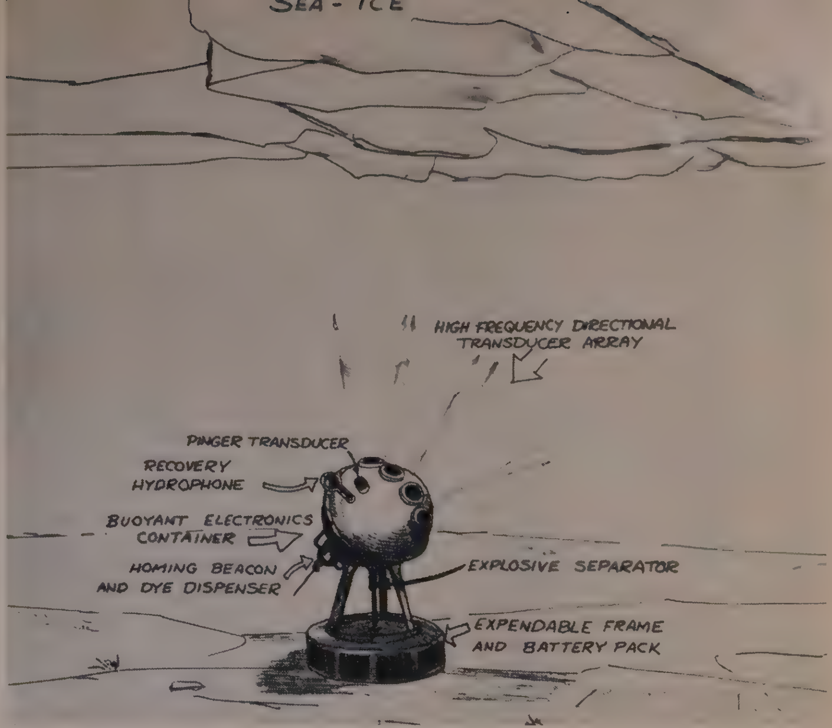
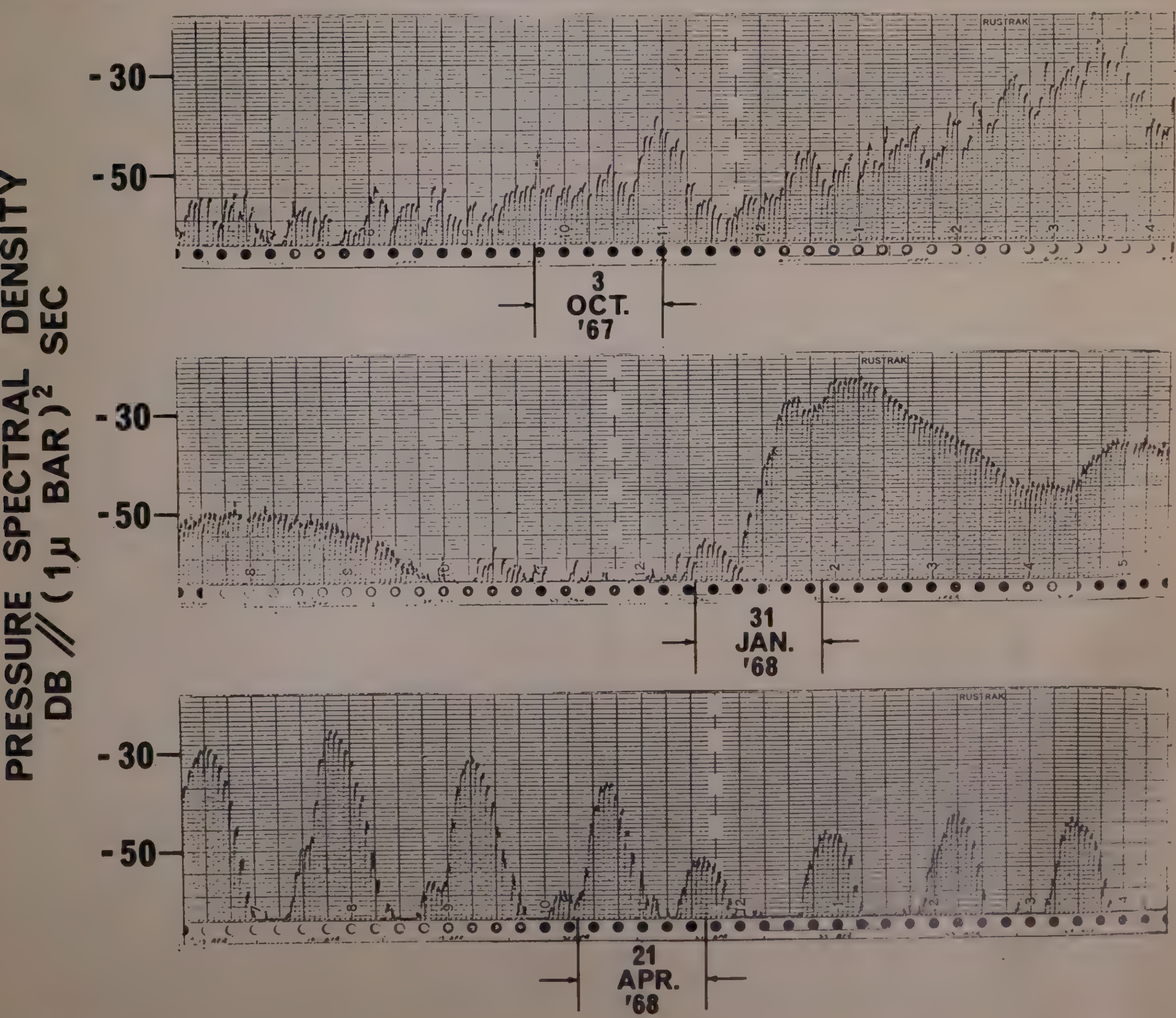


Figure 7. The CLAM — a proposed underwater observatory for obtaining time-series measurements of high-frequency underwater acoustic ambient noise and reverberation.

quencies above 20 kHz.

Our success and experience with the RIP's has encouraged my co-workers and me at DREP to propose another type of under-ice acoustic remote-sensing station for the purpose of obtaining year round measurements of high frequency reverberation and ambient noise. A sketch of such a device, called a CLAM is shown in Figure 7. The CLAM (an acronym for "Comprehensive Long-term Arctic Measurements"), is to be designed to measure ambient noise in frequency bands between 20 kHz and 120 kHz as well as the reverberation strength under sea-ice as a

Figure 6. Strip chart records of underice ambient noise in the 150-300 Hz band for weekly intervals in October 1967, January, 1968, and April 1968. The envelope of the noise intensity is formed by the hourly noise samples.



function [illegible] the angle of incidence over the s[illegible]quency ranges. We would expect [illegible]construct two identical CLAM's [illegible]all them in about 100 m of water [illegible]e summer and recover them the next. [illegible] intelligently interpret the vast quantities of data a CLAM would record it will also be necessary to perch an unmanned land-based sensor on a nearby cliff to photograph the ice surface at intervals coincident in time with the measurements being made in CLAM. It is possible that telemetered radar images of the ice surface would provide more suitable information. In any event, the local air temperature and wind speed would be required for an interpretation of the high frequency ambient noise.

In conclusion: I have described some features of acoustics under sea-ice and in particular, the fact that there is very little information available for frequencies above 20 kHz, which are those most applicable to short range, high definition sonars. Measurements of ambient noise and reverberation for high acoustic frequencies are badly needed. These measurements could most easily be obtained in the Arctic by the use of automatic undersea observatories such as the proposed CLAM.

---

(7) NEW CONCEPTS IN TECHNOLOGY & TECHNIQUES IN UNDERWATER OPERATIONS:

THE COLD WATER DIVING SUIT

by M. D. Wright*

If the underwater construction industry is ever going to grow on a practical foundation, it must be able to use divers in much the same way that personnel are used on the surface; for reasonable working periods, and with reasonable support requirements; in reasonable numbers and with reasonable productivity; with sufficient safety and reliability that careful planning can be done. At the present divers are too often divers first and trained personnel (trained in other than diving) second. And what is considered reasonable for divers is often orders of magnitude less than what is reasonable for surface workers.

With many of the problems of long exposure to pressure almost if not completely eliminated by saturation diving techniques, heat loss of diving personnel has become the major limitation to working periods underwater. In Canada we have an abundance of cold water, and it is not difficult to obtain the type of thermal environment encountered in almost any area or depth in the colder parts of the Continental Shelf. In 1957 a major requirement for underwater time in very cold water was encountered in Northern Ontario, and our participation in this program led to a strong appreciation of the many problems which we felt would be encountered in cold water work in general. This lead time has helped us achieve a workable solution to cold water work.

There are two general types of protective dress; those which use insulation to prevent the loss of body heat, which we call Passive, and those which add heat from an outside source to make up for heat lost through the insulation, which we call Active. The former include the dry suit, where a waterproof covering is worn over fairly conventional insulating underclothing, the wet suit, where a tight fitting suit of unicellular neoprene foam acts as an insulation layer, and various variations such as dry suits constructed of wet suit material, or wet suits in which a communicating cellular material is supplied with gas so as to eliminate volume reduction with increasing water pressure. In general, with 45 to 50°F water temperatures, permissible working times are restricted to from 25 to 45 minutes depending upon the exertion level.

Under the active heading, heat has been supplied either by electrical means or by open (or closed) circulation water systems. Under the former come the U.S. Rubber Electrically heated suit which used a network of fine wires within the suit to supply heat in the range of from 300 to 600 watts, and the Piel Suit in which the easily broken wires are replaced by mercury under moderate pressure in capillary tubing. Hot water heated suits of the surface supplied type have been used by Westinghouse and the U.S. & Canadian Navy, and here the equipment was of the open circuit type, that is, the water was allowed to flow out from under the insulating suit into the ambient water. This method is not particularly efficient using only 4 to 6% of the surface-generated heat. Others such as Saunders Associates have proposed a closed circuit hot water heated suit whereby a diver carries an Isotope unit that heats the water which is then circulated in a network of tubing around the diver. The open circuit hot water heated suit has performed quite well on several jobs at depths to 300 ft, but did not function well on Sealab III.

In considering the design of a thermally protective suit, we found an extensive value analysis was necessary, and in order to obtain a list of requirements, we had to draw up a series of theoretical operations thus defining a hypothetical operational envelope. When we weighed the surface supplied Active suit against the requirements two principal defects were noted; The umbilical requirements made the employment of any number of divers at saturation depths a rather frightening thing to contemplate because of the problems of fouling, and the energy cost for a similar operation (especially in the Arctic) became almost unreasonably high. We wanted to be able to use the umbilical as an optional device, possibly as a guide line, for a free swimming diver rather than as a burden.

Accordingly we decided to evolve an efficient insulation system first, assuming that the greater success here, the easier would be the heat addition problem. We also decided that we could only achieve a reasonable package if we were to approach the problem from a systems point of view. We would not divide the equipment up into breathing apparatus, face-mask, etc., but would use the operational requirement to define things like visual angles, head movement, clearance dimensions and the like.

The detailed reporting of the parameters involved are beyond the scope of this paper but I can summarize them in saying that we wanted the diver to be able to communicate with adjacent team members (and the surface if need be); have a near normal visual field; be free to swim; be depth and attitude stable; and be able to work at moderate exertion levels for about 6 hours in 35°F water.

By April 1967 we were able to support a resting diver for 6 hours in 40°F water without the use of external heat sources. The way in which this was done may be summarised:

1. All significant heat leakages were reduced as much as possible without unduely interfering with mobility,

2. Care was taken in the anthropometric design to avoid pressure on those parts of the body where moderate local pressure can cause vasoconstrictive effects,

3. An insulation system was devised in which the behaviour of both the gaseous and the solid components were considered under pressures of from 15 psia to 600 psia,

4. Attitude stability was made a major requirement in order that the diver could work in any position necessary, avoiding prolonged pressure on the lower extremities.

These points might seem obvious, but the problems with maintaining a given

* [illegible] pace Developments Limited

thickness of insulation around the diver's head without having too much buoyancy or mass required a one year program of design and prototype development. Contrary to Oriental opinion, all occidentals are not built alike, so that anthroprometric problems were consistent only in their difficulty. We had to develop non return valves (to allow the venting of excess pressures within the insulation layer) which did not leak in the reverse direction yet which would open fully under low differential pressures.

Briefly, the suit now consists of a double layer garment between which the insulating material (of nylon fleece and aluminized fabric) is maintained within a dense gas (such as Freon or Sulphur Hexafluoride), the outer and inner layers being water tight and impervious to gas. The diver is thus inside an insulation envelope, and is exposed to his breathing gas which cannot contaminate or be contaminated by the insulating gas. Valves located on the ankles and upper part of the suit vent excess gas, and the insulation at the extremities (where pressure variations are greatest) have a high compression modulus as well as being contained within an outer suit construction having minimal elasticity.

It was realised early in the program that there was little that could be used off-the-shelf, and so an extensive components-design and standardization program was set up and maintained, in which future evolution of the design was always considered in order to reduce obsolescence. Thus by freezing component designs early in the development we were able to achieve high reliability of most of the prototype design consequently reducing the amount of time spent on jerry-rigging solutions to minor problems.

The suit consists of an inner butyl skin-tight suit acting as the barrier between insulating and breathing gas (although in practice the breathing gas within the body of the suit cannot find its way back into the breathing system and is used only to prevent squeezing of the diver), an insulation cover-all is then donned, and the two piece outer urethane rubber suit is put on and zipped up using a sealing zipper. The inner suit seals to the outer suit at the wrists and neck. Gloves and a hood/helmet assembly are then add , sealing in turn at the wrists and nec Malleable gel-filled sealing cushions are used around the face and on the oronasal mask (which has a built-in microphone). The face is covered by a tri-planar polycarbonate faceplate which swings up over the fiberglas hard-hat (freflooding) to store on the forehead when opened. Means are provided to keep the pressure equalized on both sides of the eardrums irrespective of the depth or diver attitude, and the inner cavity of the suit is maintained at a pressure not in excess of 12 feet of depth greater than the diver's working depth, thus preventing squeeze and eliminating ballooning. The buoyancy variation is thus only a function of insulating gas volume, any by maintaining the gas pressure here slightly less than water pressure, the preload on the insulation minimizes volume changes.

At present a breathing set is being integrated with the suit, so that the counterlung system may be located within the insulation layer, further extending the maximum exposure time.

Under-ice experiments in biology

by Dr. J. Kalff*

Until the early 1950s biological research in the marine and freshwater environments consisted very largely of taxonomic studies. Experimental studies date from the last fifteen years but have almost all been restricted to experiments carried out during the portion of the summer when the waters were ice free and thus most resembled a temperate zone aquatic environment. These studies, valuable in themselves, could reveal little about adaptations and survival mechanisms during the 9 to 11 months when most arctic waters are ice covered. The result is that our knowledge about the activities of plants and animals living under the ice is rudimentary. The Arctic Char is a valuable resource for which premium prices are paid in the cities of Canada and the U.S.A., yet we know virtually nothing about the breeding biology of the fish and the hatching of the eggs, which apparently takes place approximately in early April when the lakes are covered with 5 to 7 feet of ice. Why do the eggs hatch at this time when snow covering the ice prevents nearly all light from entering the lakes and when the quantity of zooplankton available as food for the newly hatched fish is near the annual minimum? In view of our lack of knowledge of the biology of the char and other polar fishes it should not be surprising that our comprehension of the activities of the remaining species of plants and animals, which are of no immediate commercial value, is in most cases even smaller. Yet these plants and small animals form directly or indirectly the food of the fishes and for that reason alone merit investigation. Is it their lack of abundance which is largely responsible for the slow growth of such fish as the Char, which does not reach a maximum length or weight until they are about 18 or 20 years of age, and who may live to the ripe old age of 40?

The first comprehensive year-round investigation of an arctic aquatic habitat, with its plants and animals, their abundance, growth rates and food habits is now under way in a lake near Resolute Bay, Cornwallis Island, under the sponsorship of the International Biological Programme (I.B.P.) and financed by the National Research Council of Canada.

The elucidation of arctic food chains and of the energy flow between trophic levels is, however, only one of the aspects of arctic life that warrants investigation. A second and equally significant area involves experiments that will provide insights into the physiological and biochemical adaptations necessary in organisms which live in cold waters.

Scuba diving gear has been used to a limited extent to observe the behaviour of fish and large plankton organisms under the ice. A Fisheries Research Board of Canada project has used Scuba divers to set gill nets under the arctic ice and to collect fish caught in such nets. Divers play an important role in the cooperative lake study at Resolute Bay where they collect quantitative samples of the bottom vegetation, inject tracers into small chambers they place over portions of the vegetation in order to measure the rates of photosynthesis, observe the activity of small organisms living on or just above the bottom which are infrequently caught with sampling devices, and where they observe the schooling and feeding activity of the Arctic Char as well as the functioning of the sampling devices.

The greatest handicaps associated with cold water research are, however, not the result of the usual absence of Scuba divers from arctic studies or due to problems associated with logistics or to an absence of suitable and sophisticated instrumentation. The two greatest handicaps may well be the difficulty of enticing scientists to work in the north and the problems involved in the utilization of equipment designed for temperate conditions in cold environments. A serious handicap to the utilization of available instrumentation and equipment for field work is the absence of a commercially available ice-hut which is light, readily transportable and which can be readily erected over a sampling hole on the ice. One such small hut, folding into a package of 7 x 4 x 1 feet and weighing 100 lbs has been designed by the Defence Research Board of Canada for its personnel only (Ganton, 1968). The hut, including a kerosene-filled stove, can be readily hauled on a sled. Such a shelter not only prevents the freezing of sampling gear but also permits the manipulation of the collected samples prior to taking them to the field headquarters. Such a small hut would most likely find a ready market with ice-fishermen in the temperate zone. The Board has also designed a larger shelter for its personnel which, if produced commer-

*Department of Zoology,
McGill University

cially, could serve as a suitable field headquarters for a variety of studies in isolated areas. The 7 x 20 ft. shelters have the ... three layer sandwich type walls utilized for the smaller huts. This sandwich consists of an inner translucent vapour barrier, an outer vapour-permeable windproof shell of nylon "spinnaker cloth" and batts of Dacron fibre insulation in between. The larger shelter, excluding the foam plastic floor, weighs only 220 lbs.

Even though some kind of shelter has to be available to an arctic worker, there are many occasions on which he has to manipulate samples at temperatures below freezing. This chore would be greatly facilitated by the availability of surgical-type rubber gloves with heating wires embedded in the rubber. A small back-carried re-chargeable 12 or 24 volt powerpack could provide the power for one or two hours' work. Such gloves would also be valuable to such people as oil-rig workers in the north or telephone linemen in the winter at our latitude.

The microscopic organisms of the sea and lakes can usually be readily collected by sampling bottles. The collecting of the larger plankton organisms and fish has to involve nets and traps. Hauling plankton nets or setting gill nets under the ice by means of manually operated ice-jiggers is feasible but slow. The development of a small, light-weight electric vehicle to which a net could be attached and which upon release in the ice hole would home-in on a beacon set in a hole some distance away would greatly facilitate the study of fish or zooplankton and may have commercial applications.

I do not, however, want to leave you with the impression that the frequent lack of suitable equipment and facilities for field and laboratory research are the only remaining impediments to much more extensive and intensive studies of our cold-water resources. The high cost of northern research, especially of travel and logistics, makes it difficult for young university based scientists who are not yet wedded to temperate zone research problems and who characteristically have small research budgets, to undertake cold-water or other biological research in the arctic. The result is a general unfamiliarity with and wide-spread lack of interest in the north on the part of the scientific community which in turn is partly responsible for the small amount of money earmarked for northern research projects and in the near absence of the necessary research facilities for the study of our cold-water and other biological resources.

Reference

Ganton, J. H. 1968. Arctic field equipment. Arctic 21: 92-97.

Observing and recording underwater phenomena

— present methods and feasibility of new systems in geological exploration of the sea

by Andre M. Rossfelder*

Geological exploration of the sea has become a wide field of activity which covers not only stratigraphy and tectonics of the undersea layers, but their geophysics, geotechnique, geochemistry, sedimentology, mineralogy, as well as the study of the hydrodynamic and biological processes which influence them. Few underwater phenomena are outside the range of interest and field of observation of the marine geologist.

His world is a multi-dimensional one. His scope of work compels him to wander across the underwater space, to hover on the seafloor, to probe the subbottom, to sense the waters, and to travel along geological time. Freedom of motion is his prime requirement.

Wittgenstein says somewhere in his "Tractatus" that the limits of everyone's world are the limits of his language. But a language is built by the ways and means one can perceive his world and act upon it. In this ocean environment highly unfit for our feet to move in, our hands to probe it, and our eyes to sense it, the build-up of our language depends more than ever upon our tools. We have to enter in the ocean fully instrumented and we have to instrument it in order to open the necessary channels for communication and action.

This is obviously why oceanology has had to wait so long before expanding. The overall technology was not mature for answering its need. But finally we have started to get equipped and we are now at the threshold of a time when undersea geology is sufficiently armed for generating the discovery and development of new resources and for consequently justifying and entertaining its own growth. The test of economic practicality has eventually come to endow the geological exploration of the sea with an A-1 credit rating that the exploration of space still longs for.

The tasks — Yesterday and Today

Twenty years ago, marine geology barely existed. There were probably no more than twenty or thirty people claiming to be this paradoxical type of scientist which study earth science where, as everybody knew, there is water and no earth. Some tools such as echo-sounders, sea-floor samplers, or scuba gear were already there. Undersea photography or continuous subbottom profiling were at a very infant stage. Other instruments did not even exist: thermoprobes, magnetometers, undersea vehicles with sampling capabilities, geotechnical instruments for in-situ measurements, and, last but not least, drilling vessels.

The check-list of a diving geologist in 1949 included essentially a hammer, a shopping bag for the samples and some miscellaneous lobsters, a board with inclinometer, compass and pencil, a camera and some marking floats. A handy vehicle consisted of a rope towed by a surface craft provided with a kind of trilobate trapeze to hang on and a bell button with an electrical conductor to ask the craft for more or less rope or for more or less speed. This vehicle was efficient for covering a large ground in preliminary surveys.

A basic difference between a diving engineer and a diving geologist was already there. The tasks of the diving engineer generally require on-the-spot jobs. The tasks of the diving geologist require mobility and extension. Exploration implies endurance and range. The diving engineer is satisfied with undersea shelters or diving systems of elevator-type, while the diving geologist looks for instrumented vehicles and research submarines. These two basically different needs cannot be solved through the same approach.

The main areas of interest of what can now be considered as marine geology were, around the end of WW II, the study of shoreline processes, the tentative interpretation of seafloor topography (why continental shelves, island arcs, trenches, atolls?) and marine sediments. We were staying and working at the interfaces.

Today shoreline processes are getting out of our interest to be left to the coastal engineers and the focus is definitely upon a general, overall approach of the stratigraphy, tectonics, and sedimentology of the sea floor. Something has happened: we have discovered that the ocean floor is neither a mere extension of the continent or a quiet sedimentary carpet upon some steady mantle, that it involved something more than marine transportation and deposition, and that it has a geology of its own, implying a particular history and a present active life, as exemplified by such concepts as seafloor spreading or undersea erosion. In applied research, the

*... Institution of Oceanography, ... California. ... with Tetra Tech, Inc., ... Jolla, Calif. 92037

field of activities has considerably expanded. The marine geologist is no longer called just for investigating sedimentary processes alongshore, beach protection, harbour or marinas projects, but to do everything undersea that he could do on land: taking documented samples, mapping outcrops, deploying geophysical operations, controlling drilling outputs, asserting mineral resources, doing site surveys and geotechnical investigations, etc.

Three factors have been deeply influential for this expansion of status: undersea warfare and the need to know more about the features and properties of the seafloor, undersea mining, and offshore petroleum. I am one of the optimists who, after watching the growth of the geological exploration of the sea during twenty years, believes that its exploitation phase will mean that by 1980 a third of the world oil production will come from under the sea and that active mining operations will be carried to the deep parts of the ocean for copper, nickel and manganese. Now another thing has happened in all these various trends: the opening of the Arctic Ocean to geological exploration. From the point of view of basic research, it is the last of the unknown oceans. It will likely tell us many things in the global tectonics of the ocean floor. From the point of view of applied research, we do not know its resources, but we already suppose them to be very huge. From the point of view of instruments and operations, we have to conceive, design and assess a whole new set of tools and procedures in order to cope with two unusual environmental constraints: a barrier between the undersea world and the atmosphere — the ice pack — and the adverse atmospheric conditions most of the year.

The ways and means — Yesterday and Today

What are the hardware and procedures for carrying on the geological exploration of the sea at a pace, cost, and effectiveness matching these prospects? The list of the tools which are available for such exploration is in everybody's mind and, instead of redoing their taxonomy, let us discuss a different and more relevant problem which is too often overlooked: how to set-up an integrated operation which fulfills the required tasks at the best cost/effectiveness, or, to be more explicit: how to fit the tool to the task, the tools together, the operational procedures to the tools, and also when to say "there is a better way to do this job", how and when to develop new tools or new procedures and from the new components build new operational systems.

Oceanographic hardware and procedures have developed under the stress of two prevalent concerns: either we want information of better quality or we want operations of better efficiency. The instrumental concern drastically prevailed upon the second one, and we are at a stage in oceanography where a wide range of instruments has been developed in order to get data of higher accuracy or resolution, without a similar improvement in their operational qualities — reliability, ruggedness, deployment practicality, costs, etc. The instrumental concern has now to yield to the operational one.

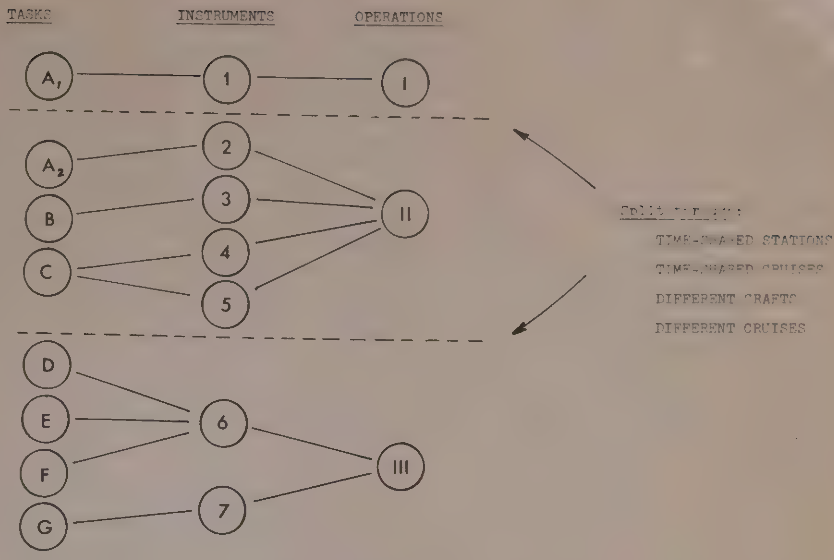


Figure 1. Coupling Task-Instrument-Operation

The most important problem which faces the scientist or engineer in charge of planning, instrumenting, staffing, and implementing a survey is, evidently, the way everything will eventually work at sea. To fulfill the scope of work through a smooth cruise, he has to joggle with three sets of parameters, the tasks, the instruments, and the scheme of operation: What tasks will cover the scope of work, what instruments will insure the tasks, and what operational set-up will be required? Tasks, instruments, and operations have to be continuously reconsidered until a satisfactory layout is reached through these successive tradeoffs.

Figure 1 summarizes the process. For example A can be an actual sampling operation of the seafloor requiring a dredge 1 and a sampler 2. B can be a temperature profile satisfied with an expendable bathythermograph 3, and C a measurement of currents which can be done through drogues 4 and flowmeters 5. D, E, and F may be various tasks, such as bathymetric navigation, echo-sounding, subbottom profiling, DSL surveillance, etc., all of which can be insured by a single echo-sounder 6. And, G, is a magnetic profile through magnetometer 7. Deployment of these instruments will necessitate a dredging tow in Operation I, a wireline work on station which can be accompanied by miscellaneous measurements in Operation 2, and an underway survey in Operation 3. The list can easily be extended and modified. What can be seen is that the final breakdown of tasks and schedule of operations have both been decided by the availability of instruments. These instruments have all essentially been designed as individual, particular tools fitted for exact jobs, with almost no respect for what the other tools are doing, can do, or require. Now, let us imagine another approach: it will consist in examining such a lay-out, not as an end-product but as the start for a new concept development where the tasks will be reshuffled and new instruments accordingly designed until reaching a scheme of operation simpler, cheaper, and faster. I believe that this is the point where we are now with our hardware and procedures. After a period of equipment diversification we should now enter into a period where instruments and procedures have to be considered as mere components for setting-up exploration systems better integrated and more effective.

It is impossible to predict what the exploration systems of the future will be, but what can be done is to briefly examine the products of this diversification — type of instrumentation, deployment procedures, supports — because the future systems will essentially result from various recombination, crossing, and hybridization between these constitutive features.

Anatomy of undersea exploration systems

First, there is the instrument. We can look at it according to the parameter that it measures or samples and we reach the current classification (bottom samplers, currentmeters, water-bottles, acoustic profilers, imaging instruments, etc.). We can also look at it from the point of view of the information channel and the situation of the various parts of the information channel in the environmental loci. Figure 2 shows this breakdown. The oldest instrumentation involves sampling operations (1), some shipborne analysis (as in 2), and some in-situ recording instruments (as in 5), but practically all other instruments are the children of the electronic age.

The way the data is stored and transmitted shows a wide range of possibilities The sensor can be:

- on a winched wireline,
- on a free recoverable vehicle,
- on an expendable vehicle,
- on a taut moored line,
- laying on or embedded in the sea floor.

The data which it collects can be:

- stored until the instrument is back on its surface support,
- stored during underwater travel and telemetered upon resurfacing,
- telemetered during underwater travel,
- received and reemitted from surface vessel or buoy, from under sea listening devices, from aircraft, from satellite, etc.

Another very important consideration is the mode of deployment and the type of support. We have used the surface vessel so long that we have a tendency to consider it as the only solution for deployment and support. However, the research submarine is available, and two new types of support are incoming: aircraft and ground-effect vehicles. Concerning aircraft, not only sensing arrays are currently deployed by helicopters, but wireline work at sea has been successfully implemented with circling airplanes. Airborne oceanographic operations involving not only remote-sensing but actual sampling and, even, coring operations, are definitely in the offing. Finally ground-effect vehicles have recently appeared. High-speed bathymetric surveys are already carried with these vehicles and we can expect that they will soon prove their efficiency in the Polar Circle where the Russians already use them. Arctic oceanography should also remind us that some unexpected types of oceanographic supports have been used there: ground vehicles such as sleds or crawlers and even warm, immobile barracks, drifting on ice islands in the midst of the pack.

Instrument concept and design and operational procedures can consequently be considered as related to the possible supports:

- surface
- airborne
- underwater
- ice pack

Due to the importance that subsurface operations will likely present in the geological exploration of the Arctic, I would like to stop briefly on the subject of the undersea vehicles and habitats and outline their present inventory, not for classification purposes, but again to stress that there are also more possibilities here than generally recognized.

Undersea "wet" vehicles will likely have a restricted role in the exploration phase even as commuter cars from undersea habitats. "Dry" vehicles are certain to play an extended part in this phase. Besides the well-known spheres, cylinders or ellipsoid operating in a neutral, self-propelled mode, with or without capabilities, we can expect more exotic types such as toroidal submarines, vehicles able to operate in both self-powered and remote-powered modes, vehicles able to suction-anchor themselves on the seafloor for coring work, negative-buoyancy vehicles travelling on the sea floor as buggy, crawler, or ground-effect vehicles, etc.

Undersea habitats are generally visualized as immobile shelters resting on the sea-floor. As such they have restricted capabilities for geological tasks, unless provided with commuting undersea vehicles. Elevator-type habitats mounted on a mooring stand with ground-traction capabilities can be of value for enduring tasks in limited areas. The concept presented yesterday at this conference by B. F. Ackerman, for a habitat inserted in the ice-pack, thus drifting, and provided with an exploration submersible, thus with reconnaissance and survey means, realize an artificial drifting ice island with far more capabilities than the natural ones. Coring, seismic refraction, and various geophysical tasks can be implemented by this way in areas otherwise almost inaccessible to current supports.

Huge undersea habitats, with limited, self-propulsion means, but long endurance and vertical mobility, may be the ultimate exploration support in this part of the world. Their feasibility is only limited by the logistic problems of transfer of supplies and personnel, which imply either the capability of thru-ice resurfacing for airborne logistics or the development of "underwater" trucks, but both solutions will likely be available in the near future.

Deployment problems involve another consideration: the linkage between the instrument and its support.

Until now, underwater work involving sampling operations was essentially carried through winch and wireline. This is a vertical, pin-point work controlled all the way by the surface vessel. The free instruments which have appeared during recent years have opened new possibilities. In fact, they are essentially the direct descendants of the tethered samplers with expendable weights which were flourishing at the turn of the century. Stronger wires and winches had eliminated the need for an expendable, non-returning weight; now, floats able to withstand deep sea pressure eliminate the need for wires and winches, and bring the expendable weight back on stage. We can be sure that free instruments will take over a large part of the oceanographic operations, as they allow for faster operations and lighter support vessels than permitted by wireline work; they also allow for simultaneous tasks with different instruments; and they widely open the doors for airborne operations. There are currently deep-sea survey programs for ocean mining purposes

Figure 2. Data collection systems

TYPE OF INSTRUMENTATION	UNDERSEA	SURFACE	ASHORE
1 Samplers (coring, water sampling)	I_1 →	sample transfer →	I_2 S R P
2 Samplers with shipborne lab	I_1 →	I_2 S R P →	P
3 Remote-sensing	I →	S R →	P
4 Tethered sensors, current-meters, TV, magnetometer, data-buoys, towed vehicles, etc.	I S →	R →	P
5 Thermosondes, probes, currentmeters, instrumented vehicles, UW operation	I S R →	→	P
6 In-situ sensors with direct transmission of data via radio, sonar or cable to shore facilities	I S →	Telemetering →	R P
7 Most of 4 with shipborne laboratory and processing facilities (computer)	I S →	R P	
8 Most of 5 with shipborne laboratory and processing facilities (computer)	I S R →	P	
9 Fully instrumented undersea vehicles	I S R P_1 →	follow-up →	P_2

I Information Source
S Sensor or analytical device
R Recording
P Processing

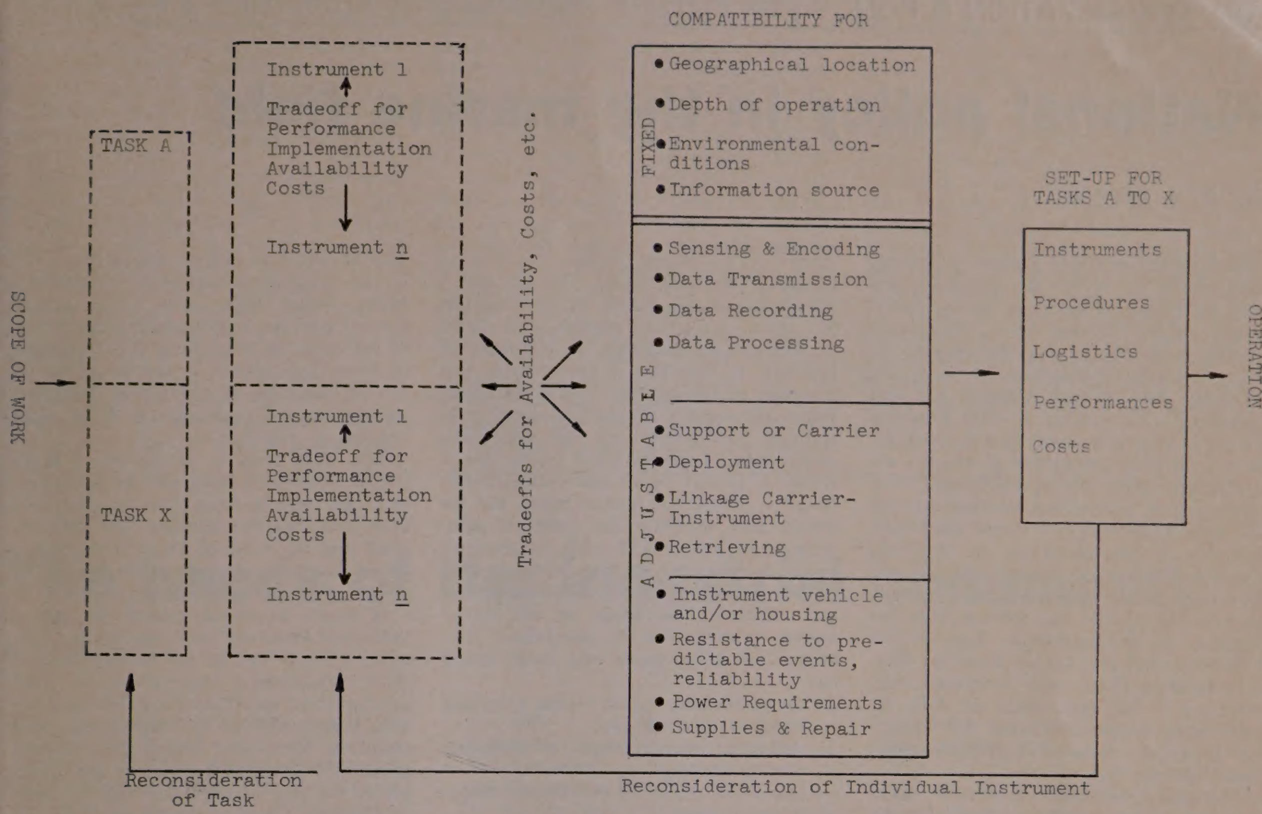


Figure 3. Instrument integration

essentially carried with free instruments. The same collection of data by wireline work would have involved a cost at least five times higher.

The next advance in free instruments may be the substitution of the expendable weight by new "buoyancy generators", but more probably it will be the intervention of active devices able to spend some time along an underwater course for carrying one or several tasks. Presently, this concept of unmanned vehicle is principally represented by devices still towed or tethered from the surface support with data-storage capabilities such as the imaging sled of Cousteau or the "FISH-type" vehicles of Scripps Institution of Oceanography and of the U. S. Navy, or with self-propelling capabilities such as the CURV or the SORD.

Altogether, consideration of linkage and relationship between the sampling instrument and the vessel during operation give us another perspective for discussing the instrumental and operational set-up of a survey, as they open another series of possibilities.

- device lowered by winch and wireline
- free passive device
- free traveling device
- towed device with data-storage capabilities
- tethered device with data-storage and self-propulsion capabilities.

This review can now be concluded if it has filled its purpose which is not to draft an exhaustive listing of every concept which can be thought of in undersea geological exploration, but to underline that if we want to match tasks, instruments and operations, there is in fact a wide array of possibilities for adapting the instruments to the tasks in an optimum scheme of operation, instead of adapting the tasks to the available instruments and being consequently bound to a compulsory scheme of operations.

But this optimization of the tools, which may mean the design of new tools, brings a last problem; their integration within the overall system. Figure 3 delineates this point. Tradeoffs between various existing instruments and/or new concepts, for availability, costs, performance, conditions of implementation, have to aim for a final system built from compatible components. Criteria of compatibility falls within two categories: the constraints which cannot be changed (geographical location, depth of operation, environmental conditions, source of information) and the variables which can be adjusted. It is through this adjustment that the compatibility of the various components and procedures within the system is eventually established. Change in the choice of the data-storage or transmission system in a component can be sufficient for allowing two tasks in a single operation. Adaptation of the deployment procedure and linkage to ship of a vehicle can permit the simultaneous use of another instrument. Inversely, mating two instruments with different ruggedness or reliability in a single deployment procedure can just be a station wasted.

As a conclusion, in instrumenting, planning and implementing undersea exploration, we have now a sufficiently diversified range of instruments and procedures to go beyond their individual characteristics and to readapt and mold them to the need of the final optimum system which can be operated at sea.

Equipment manufacturers have to look at their instruments as mere components which have to be rugged, reliable, cheap and versatile and we have to prepare ourselves for new system planning and superintendence in ocean exploration, because cost/effectiveness has come into the game and will eventually rule it.

owns the land and the wealth beneath the sea, who may exploit the wealth and how they must go about it. If property under the sea is to be used to the total benefit of all Canadians, then the Federal and Provincial Governments must formulate these laws and they must formulate them now so that action will follow the law rather than the law trying to catch up with action after it has taken place as is presently the situation.

In particular, Canada must consider and legislate on:—

1) Federal and Provincial sovereignty
2) Sovereignty of Arctic water bounded by Canadian land masses.
3) Continental Shelf

Second — Incentives to industry

Industrial initiative is based on two fundamental concepts — expansion and profitability. A third method of encouraging initiative in Canada is commonly known as Government Incentives — these in Canada have taken many forms — tax concessions for R & D, financial assistance to pay for research programs showing export potential, and capitalization assistance for building and equipping production facilities.

Most of these programs such as PAIT, IRDIA, etc., have unfortunately been oriented primarily toward "Research". The problem here is that research offers long term potential but Canada has a need for short term returns as well as long term. To this end, assistance programs must be oriented more toward — innovation, development, and marketing. The second problem is that existing incentive programs are oriented toward R & D of small unit value and are not suitable for programs involving heavy expenditures in feasibility studies and market studies and high prototype costs.

Oceanology is a perfect example of a field in which existing programs are ineffective and where the above recommendations would be most advantageous since:

— This a new field
— The payoff is very long term
— The risk is very high
— Much work must be done in the innovative areas

Please don't misinterpret this as an indictment of present Incentive Programs — our company alone exports over 85 per cent of the products manufactured in our Canadian plants, due to a great extent to IRDIA and Vote 5 type assistance programs. These programs must now, however, be expanded and changed to meet the changing technological and marketing conditions.

Third — Government research agencies

To date almost all of the Oceanographic work in Canada has been carried out by government-controlled facilities, hence of the 25 million dollars expended last year in this field by Government, practically none of it went to industry. It seems incongruous to me that the Government should allow this to happen, particularly when you consider that Government agencies cannot *export* their expertise, their products, or their capabilities to assist in any balance-of-payments situation we might have. Only industry can compete and sell these capabilities in an export market.

What should these Government agencies do?

(a) They must communicate with industry and disseminate information to enable industry to gain an insight into their programs and their hardware requirements.

(b) Provide industry with the opportunity to develop instruments, concepts and systems to meet their operational needs. Perhaps these items have export potential, who knows? But make the specifications realistic.

(c) Get patentable and saleable products out of the labs and into industry. Canadian Patents and Developments Limited was established for this exact purpose — to encourage industrial use of government developments which had sales potential.

Fourth — Co-ordination agency

In Canada, there is a need for a central programming co-ordination body with basic objectives similar to those established for the proposed National Oceanic and Atmospheric Agency in the United States. Such an agency in Canada should be made up of representatives of universities, government and industry. The needs for such an agency include the following:

(a) Our financial resources in Canada are limited, therefore, we must concentrate on a limited number of broad-based but effective programs. In this regard, we should seek co-operative programs with other countries to avoid duplication, keep costs down and enhance the image of Canadian technical and hardware capabilities in other countries.

(b) Government to date has formulated no national programs or policies which would tend to encourage Canadian industry to invest in this field. Such an agency would formulate that policy, finance and administer the long term programs which should be the base on which Industrial manpower, facilities and financial planning can be carried out. The Canadian Council on Oceanography is obviously working toward this end. However, until their terms of reference are expanded to include the control of funding, authorization and initiation of long term programs including Government and Industry, their contribution cannot be fully effective. It is hoped that the Science Council, Committee on Marine Science and Technology will consider these recommendations in their forthcoming report. If they fail to accept this challenge the consequences are obvious — foreign control and exploitation of Canada's largest natural resource, potential trade deficits, technological stagnation in Oceanology, and degradation of Canada's prestige. That is a high price to pay for complacency.

Educational Institutions

Oceanology in Canada must have a sound technological base in ocean science and engineering if the programs discussed at this conference are to be effective. This academic base can only be supplied if Canadian universities establish Faculties of Ocean Sciences to formulate educational programs and provide a steady stream of oceanographers, engineers and scientists. In this regard, I am particularly happy to see that McGill University co-sponsored this conference and donated these facilities.

Canadian industry needs these people not only to satisfy domestic requirements but to enable Canadian companies to compete internationally for export business.

Mission-oriented companies

At present, the Oil Industry represents the largest commercial investment and the greatest activity in exploiting Canada's resources. Most of these companies have developed their rigs and equipment in other countries and have gained their operating experience in such areas as the Gulf of Mexico and the North Sea. In coming to Canada, many have shown a definite interest in using Canadian capabilities, facilities, and people to meet these local requirements. Others, however, are drawing their talent, equipment and services from foreign areas. As a result, we find rigs being designed in the United States for use in Canadian drilling programs with foreign suppliers being specified for equipment which could be manufactured right here in Canada.

Obviously, part of the responsibility for this situation must rest with Canadian Industry for not demonstrating sufficient initiative and desire to take risks. Mission-oriented companies like ourselves have a basic requirement to operate efficiently and profitably; however, again like ourselves, they have an equally important responsibility to be "Good Corporate Citizens of Canada". I think the Canadian Equipment Industry has the talent and capability to meet these requirements if given the opportunity.

Canadian equipment industry

The preceding discussions may give the impression that all responsibility for expanding Oceanology in Canada lies with government, universities and user companies. Such is certainly not the case. The Canadian Marine Equipment Industry has been equally responsible for the slow growth due partly to our natural hesitancy to take risks and our basically conservative corporate personality. It is gratifying to note, however, that the formation of the Canadian Association of Marine Equipment Industries (CAMEI) shows every indication that this industry is willing at last to take on a responsible and dynamic role in the marine and oceanographic future of Canada. To fill this role, industry must adopt a new outlook in several areas:—

First, they must be optimistic — Oceanology offers opportunities for sales growth in Instrumentation, Tools and Manipulators, Salvage Equipment, Energy Systems, Environmental Systems, Heavy Equipment Handling, Weather and Navigation Systems.

When you consider these items and Canada's undersea potential, there is obvious reason to be optimistic.

Second, they must take risks. Every

other industry does. The oil industry invests millions of dollars in dry wells. Shouldn't the equipment industry equally take a risk?

Third, Canadian industry must sell, sell their capabilities, not as catalogue salesmen selling pumps or motors, but as professionals with an appreciation for customers' requirements, the environment in which the people are working and the financial restrictions under which they must operate.

Fourth, industry must communicate — with each other, with users and government agencies, with universities and with the export world. They must express their interests, show their enthusiasm, show their capability, and I think eventually they will show a profit.

Conclusion

I think it is apparent to everyone who has attended this Conference, that Oceanology as an Industry or as an Academic Discipline has a tremendous future but much work has to be done individually and collectively. This is not a field for "crash-programs" which are often wasteful of money and resources. However, action should not be postponed with the argument that for long-term objectives it does not matter if we begin this year or next year.

To summarize:— (a) we need *more effective* communications between industry and government, industry and educational institutions and with other members of related industries; (b) we need more co-ordination and attention by government to financing, legislation and the development of this technology; (c) we need more oceanographic faculties in universities to develop the knowledge and manpower to support this discipline; (d) we need industry to take more risks and show more innovation. In short, we need more of everything with emphasis by government, industry and education on specialization.

Our ocean resources developed over eons of time and have been available for exploitation for thousands, perhaps millions of years. Let's hope it doesn't take that long to find these resources and learn how to use them effectively.

The exchange of scientific & technical data

by M. J. Colpitts*

CLOSING REMARKS CONFERENCE CHAIRMAN

At this stage, it is customary for the chairman of a conference to undertake a summary. I am going to suggest that all indicators demonstrate that this first conference in Canada, on "Man in Cold Water" has been a success.

For the Conference Committee, it has been a pleasant surprise — our estimate of attendance is in the order of 300, which could have reached 400 if Air Canada had not been on strike. At this particular time, I would like to thank the 30 members of the press who registered for the excellent support they have given this conference. Part of the purpose of the conference was to increase the public awareness of the opportunities in Oceanology for Canada and the press has assisted greatly. As all here are aware, we will require moral and financial support from the general public.

On behalf of the Conference Committee, I would like to thank George Burt for his kind words of commendation. In addition, I would like to thank all those who worked diligently behind the scenes, the panel participants and particularly the delegates who are, of course, the main reason for the success of any conference. We are also most appreciative for the support of McGill University and also the federal Department of Industry, Trade and Commerce, who jointly sponsored the Conference.

I would like to make a few remarks about the term "Oceanology" which has been used quite often during this Conference.

A number of words have been used to describe matters relating to the oceans. These have included inner space, hydrospace, underseas and others. However, one term "Oceanology" continues to persist and is expected to evolve into the acceptable encompassing term. It was used in the title of the first international conference "Oceanology International '69" in England and Senator Pell of the U.S.A. is an articulate advocate of its use.

Oceanology is intended to encompass all matters related to the oceans, such as science, engineering, law and economics.

This Conference was organized by some individuals who were enthusiastic about Oceanology in Canada and convinced that we were geographically, scientifically and technically well endowed and, in addition, that if Canada was to develop and maintain a leading position in the field, now was the appropriate time to bring the participants together. The participants have included the scientists, engineers and others from the government, industrial, university and investment communities.

The committee considers that the several aims of the Conference were attained, which are as follows:

- to increase the public awareness of the importance of Oceanology.
- to demonstrate the state of Canadian capability in Oceanology.
- to provide a forum for the exchange of scientific and technical information.
- to provide for future co-ordinated effort in Oceanology in Canada.

Based on discussions and remarks among the delegates, the Conference Committee would like to make two proposals:

1. A Canadian Oceanology Society be formed to perpetuate the interchange of scientific, engineering and other information initiated by this Conference.
2. A conference with a similar broad theme be held next year.
3. The existing Conference Committee undertake to bring these two proposals into being.

In explanation, I would suggest that the value of another conference is self-evident. A society or similar organization is necessary to formalize the process of exchanging information in Canada. In addition, such societies have been formed in other countries (the Society of Underwater Technology in Britain and the Marine Technology Society in the U.S.A.) and a Canadian Society appears necessary so as to participate internationally. Also, Oceanology International, a biennial Conference and Exhibit, will be hosted, in turn, by a number of countries. However, the International Advisory Committee, on which I represented Canada, agreed that only a learned society in a country could be the host. Therefore, if we hope to have Oceanology International held in Canada, we require an oceanology society. I am hopeful that Canada may be considered as host in 1975.

Gentlemen, may I have your reaction to these two proposals?

By the high decibel level of the clapping and the large number of affirmative responses from the delegates, as Conference Chairman, I will take the liberty of declaring that the proposals have had a very enthusiastic response.

We look forward to all becoming members of the society and attending the Oceanology Conference next year.

*Chief, Marine Division, Aerospace, Marine and Rail Branch, Department of Industry, Trade and Commerce, Ottawa.

A letter
to the

A major obje nd
Commerce is
development, tech-
niques for ex ces.

Within this c nd
Commerce w sity the
Man in Cold he
conference s lity
in Oceanolog rtance
of this field t e
co-ordinated

We would lik ts
made this co nce
participants
community; t
technological w
field; and Mc
conference a

Martin J. Colpitts
Chief, Marine Division
Aerospace, Marine and Rail Branch
Department of Industry, Trade
and Commerce

Copies of these proceedings may be obtained from the Canadian Society of Oceanology, P.O. Box 2442, Postal Station D, Ottawa 4, Ontario. Price $5.00